EFFECTS OF SOME PHYSICAL AND CHEMICAL PROPERTIES OF SOILS ON THE GROWTH OF *PINUS CARIBAEA* VAR. *HONDURENSIS*.

By

ZOEFRI HAMZAH

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA
1968

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation of the tireless and patient guidance rendered by Dr. William L. Pritchett, Adviser and Chairman of his Supervisory Committee, during the preparation of this dissertation.

Appreciation is extended to Dr. Wayne H. Smith, Assistant Professor of Forestry, Dr. Harold B. Clark, Professor of Agricultural Economics, Dr. Ray E. Goddard, Associate Professor of Forestry, and Dr. Hugh L. Popenoe, Associate Professor of Soils and Director of International Programs, for their constructive criticism and invaluable assistance in the presentation of this manuscript.

The author is also indebted to Mr. L. S. Lindo, Chief Forest Officer of British Honduras, for the numerous facilities provided in conducting the field phase of this research and for the permission to use official records and information in this dissertation. The author also is grateful for the cooperation and assistance of each of the technical and administrative personnel of the Forest Department in Belize City and in the Forest Divisions of Savanna, Melinda and Augustine. Without their assistance in the planning, housing, transportation, sampling, typing and other services this study would not have been possible.

Thanks are due to Mr. Alfred L. Denkewalter, Mrs. Mary C. McLeod and Mr. Hubert L. Carver for assistance in chemical procedures.

He is indebted to the Rector of the Institut Pertanian Bogor, the

Dean of the Bogor School of Forestry and the Staff of the University of Kentucky, Office of Overseas Programs, who were instrumental in his coming to the United States and for their confidence in him as a scholar at the University of Florida. He thanks Mr. Reed N. Lewis of A.I.D., Washington, D.C. for financial support during the last twelve months.

He is grateful to Mrs. Lillian S. Ingesloth for the excellent job of typing and Mr. Joseph Herwig, who voluntarily prepared several graphs in this dissertation.

Last, but not least, the author wishes to thank his wife and daughter in Bogor, for their patience, understanding, support and cooperation during four years of separation which preceded the award of the pursued degree.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ii

LIST OF TABLES vi

LIST OF FIGURES x

INTRODUCTION 1

REVIEW OF LITERATURE 13

- Climate 13
- Geology 17
- Soils 21
- Chemical Properties of Pine Ridge Soils 30
- Classification of Soils in British Honduras 36
- Botanical Characteristics 41
- Mycorrhizae 44
- Associated Vegetation 47
- Humus Actions 51
- Growth 54
- Management 57
- Utilization 58

MATERIALS AND METHODS 65

- Studies on Soil Properties and Tree Growth in British Honduras 65
  - Sampling Techniques 65
  - Laboratory Analyses 68
  - Climatic and Environmental Data 72
- Greenhouse Experiment Involving Fertilizer Applications and Soil Water Level 72
  - Soil 72
  - Plant Material 73
  - Treatments 74
  - Measurements 75
  - Plant Analyses 77

RESULTS AND DISCUSSION 78

- Environmental Measurements 78
  - Preliminary Site Evaluation 78
  - Soil 82

Page

Climate 139
Growth Measurements in British Honduras 150
Greenhouse Experiments. 163
Effects of Treatments on Soil Chemical Properties. . . 163
Growth Response to Soil Water Levels and Nutrient Supply. 173
Concentration and Total Uptake of Nutrients as Affected by Soil Water Levels and N and P Additions 191
Mycorrhizae 206

SUMMARY AND CONCLUSIONS 210

Growth Conditions of Pine in British Honduras 210
Greenhouse Experiment 213
Optimum Growth Conditions for *P. caribaea* in a Tropical Lowland 214
Feasibility of Introduction of *P. caribaea* in Kalimantan, Indonesia 215

APPENDICES 219

LITERATURE CITED 273

BIOGRAPHICAL SKETCH 285

LIST OF TABLES

Table Page

1 CLASSIFICATION OF FOREST LANDS 2

2 PRODUCTION OF PAPER AND BOARD 4

3 CONSUMPTION OF PAPER AND BOARD 6

4 WORLD DEMAND FOR PAPER AND BOARD TO 1980 7

5. CONSUMPTION OF PAPER AND BOARD IN INDONESIA AND THE WORLD 8

6. RESULTS OF TWO PLANTATION TRIALS IN INDONESIA WITH *P. caribaea* AS COMPARED WITH AVERAGE GROWTH OF *P. merkusii* 11

7. AVERAGE MONTHLY RAINFALL IN SELECTED COASTAL STATIONS IN BRITISH HONDURAS, HONDURAS AND NICARAGUA 14

8. AVERAGE MONTHLY TEMPERATURE IN SELECTED COASTAL STATIONS IN BRITISH HONDURAS AND HONDURAS 15

9. CHARACTERIZATION OF TWO SOIL TYPES UNDER *P. caribaea* 25

10. ANALYTICAL DATA OF SOILS OF GUATAMALA ON WHICH *P. caribaea* VAR. *hondurensis* GROWS 32

11. SCHEME OF CLASSIFICATION OF SOILS 37

12. GROWTH OF *P. caribaea* IN GUYANA AND SURINAM AS COMPARED WITH *P. merkusii* IN JAVA 56

13 TIMBER EXPORTS FROM BRITISH HONDURAS IN 1952 AND 1962 58

14 HONDURAS LUMBER EXPORTS - 1955-1962 61

Table Page

15 LOG AND LUMBER EXPORTS OF NICARAGUA . . . 62

16 EXPORTS OF ROSIN AND TURPENTINE FROM HONDURAS 1957-1965 . . . 63

17 SOME PHYSICAL AND CHEMICAL PROPERTIES OF SOIL USED IN GREENHOUSE EXPERIMENT WITH *P caribaea* SEEDLINGS . . . 74

18 SOME ENVIRONMENTAL OBSERVATIONS NEAR SOIL PROFILE PITS . . . 80

19 CHEMICAL ANALYSES OF SOILS SUPPORTING STANDS OF *P caribaea* VAR *hondurensis* IN BRITISH HONDURAS . . . 98

20 ANALYSIS OF *P caribaea* NEEDLES TAKEN FROM TREES IN THE VICINITY OF SOIL PROFILE PITS . . . 108

21 PHYSICAL PROPERTIES AND MOISTURE RETENTION DATA OF SOILS SUPPORTING *P caribaea* IN BRITISH HONDURAS . . . 118

22 COMPARATIVE WATER BALANCE DATA AT SELECTED STATIONS IN BRITISH HONDURAS . . . 145

23 GROWTH MEASUREMENTS IN INCREMENT PLOTS IN THE SAVANNA PINE RIDGE . . . 159

24 GROWTH MEASUREMENTS IN INCREMENT PLOTS IN THE BROKEN PINE RIDGE . . . 160

25 GROWTH MEASUREMENTS IN FERTILIZED AND UNFERTILIZED NATURAL REGENERATION OF *P caribaea* IN THE MOUNTAIN PINE RIDGE . . . 162

26 ANALYSIS OF VARIANCE FOR EFFECTS OF WATER TREATMENTS, N AND P ADDITIONS ON SOIL pH, RESIDUAL TOTAL N, EXTRACTABLE P AND K . . . 164

27 ANALYSES OF VARIANCE FOR EFFECT OF WATER TREATMENTS, N AND P ADDITIONS ON ELONGATION DIAMETER, DRY WEIGHT OF TOPS AND ROOTS AND ROOT/TOP RATIO OF *P caribaea* SEEDLINGS . . . 177

28. ANALYSES OF VARIANCE FOR EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON N, P AND K CONCENTRATIONS IN TOPS AND N AND P CONCENTRATIONS IN ROOTS OF *P caribaea* SEEDLINGS . . . 193

Table | Page

29. OCCURRENCE OF MYCORRHIZAE AND ACCUMULATION OF N AND P IN ROOTS AND TOPS OF *P caribaea* SEEDLINGS ... 208

30 ORGANIC MATTER, C, TOTAL N, EXTRACTABLE P, K, Ca, Mg, Mn, Na, Al AND Fe IN UPPER 30 cm SOIL UNDER *P caribaea* VAR *hondurensis* IN BRITISH HONDURAS ... 220

31 PARTICLE SIZE DISTRIBUTION IN SOILS OF BRITISH HONDURAS SUPPORTING STANDS OF *Pinus caribaea* VAR *hondurensis* ... 221

32 DIFFERENTIAL THERMAL CHARACTERISTICS FOR KAOLINITE, HALLOYSITE AND ALLOPHANE ... 226

33. DISTRIBUTION OF CLAY MINERALS IN THE PINE RIDGE SOILS OF BRITISH HONDURAS, BASED ON IDENTIFICATION WITH DTA ... 227

34 RAINFALL AND TEMPERATURE FOR SOME SELECTED STATIONS IN BRITISH HONDURAS ... 230

35 AVERAGE CLIMATIC WATER BALANCE DATA FOR SELECTED STATIONS IN BRITISH HONDURAS ... 231

36 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON SOIL pH, RESIDUAL TOTAL N, EXTRACTABLE P AND K ... 235

37 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON ELONGATION, DIAMETER, DRY WEIGHT OF TOPS AND ROOTS AND ROOT/TOP RATIO OF *P caribaea* SEEDLINGS ... 237

38 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON N CONCENTRATIONS AND CONTENTS IN TOPS OF *P caribaea* SEEDLINGS ... 238

39 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON P CONCENTRATIONS AND CONTENTS IN TOPS OF *P caribaea* SEEDLINGS ... 240

40 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON K CONCENTRATIONS AND CONTENTS IN TOPS OF *P caribaea* SEEDLINGS ... 241

Table	Page

41. EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON Cu, Fe AND Zn CONCENTRATIONS AND CONTENTS IN TOPS OF P. caribaea SEEDLINGS . . . 242

42 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON N CONCENTRATIONS AND CONTENTS IN ROOTS OF P. caribaea SEEDLINGS . . . 245

43 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON P CONCENTRATIONS AND CONTENTS IN ROOTS OF P. caribaea SEEDLINGS . . . 246

44 EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON TOTAL UPTAKE OF N AND P BY P. caribaea SEEDLINGS . . . 247

45 CLIMATOLOGICAL DATA OF SOME SELECTED STATIONS IN THE ISLAND OF KALIMANTAN . . . 248

LIST OF FIGURES

Figure Page

1 Geographical distribution of *Pinus caribaea* Morelet . . . 45

2 Map of British Honduras showing the location of the pine ridges. I-Savanna Pine Ridge, II-Broken Pine Ridge, III-Melinda Coastal Pine Ridge, IV-Mountain Pine Ridge, V-Northern Pine Ridge . . . 67

3. X-ray diffractograms of Mg and K saturated clay fractions of soil used in greenhouse experiment; a = Quartz, b = Montmorillonite, c, h, i, j = Metahalloysite, Kaolinite, d = Gypsum, e = Gibbsite, f = Metahalloysite, g = Chlorite . . . 75

4. Poor soil drainage in the Savanna Pine Ridge is indicated by standing water on this fire break after an hours rain . . . 83

5. Scattered *P. caribaea* trees on a low productivity site of the Savanna Pine Ridge . . . 86

6. *P. caribaea* stand on medium productivity site of the Savanna Pine Ridge . . . 87

7. *P. caribaea* stand on high productivity site of the Savanna Pine Ridge . . . 88

8. General view of the Mountain Pine Ridge . . . 92

9. A group of *P. caribaea* trees in the Northern Pine Ridge . . . 94

10. Shallow profile in the Savanna Pine Ridge. The depth of the water table is only 40 cm. Note the dark layer is the surface horizon, and the compact subsoil . . . 123

11. Graphical representation of particle size distribution Savanna Pine Ridge . . . 126

Figure Page

12 Graphical representation of particle size distribution in soils of Broken Pine Ridge and Melinda Coastal Pine Ridge . . . 127

13 Graphical representation of particle size distribution, Mountain Pine Ridge, Northern Pine Ridge . . . 128

14 Gravelly soil in the Mountain Pine Ridge . . . 129

15. DTA thermograms of clay from soil samples taken from Savanna Pine Ridge and Broken Pine Ridge . . . 133

16. DTA thermograms of clay from soil samples taken from Melinda Coastal Pine Ridge, Mountain Pine Ridge and Northern Pine Ridge . . . 134

17 Monthly precipitation of some selected stations within the pine belt in British Honduras . . . 140

18. Monthly minimum and maximum temperature of some selected stations within the pine belt in British Honduras . . . 143

19. Balance between precipitation and potential evapotranspiration of Melinda and Savanna . . . 147

20. Balance between precipitation and potential evapotranspiration of Augustine and Maskall . . . 149

21 Effects of water treatments, N and P additions on soil pH . . . 165

22. Effects of water treatments, N and P additions on residual total N . . . 168

23 Effects of water treatments, N and P additions on extractable residual P . . . 170

24 Effects of water treatments, N and P additions on extractable residual K . . . 172

25. Seedlings in wet soil to which 500 ppm N were added at varying rates of P from left to right, 0, 62.5, 125, and 250 ppm P . . . 175

26 Seedlings in drained soil that received the same fertilizer treatments as in Figure 25 . . . 176

Figure Page

27. Effects of water treatments, N and P additions on seedling elongation 179

28 Effects of water treatments, N and P additions on diameter of seedlings 181

29. Effects of water treatments, N and P additions on dry weight of tops 183

30. Effects of water treatments, N and P additions on dry weight of roots 184

31 Root growth of *P. caribaea* seedlings in drained soil that recieved 250 ppm of P and varying rates of N From left to right 0, 125 250, and 500 ppm of N 185

32 Seedlings in drained and wet soil with no added P. From left to right No N, No N 125 ppm N, 125 ppm N 188

33. *P. caribaea* seedlings in wet soils with varying rates of P, but no added N From left to right 0, 62 5, 125 and 250 ppm P added 189

34 Root growth in wet soils Seedlings received no added N, but varying rates of P. From left to right 0, 62.5, 125 and 250 ppm of P 190

35. Effects of water treatments N and P additions on N concentration of tops 192

36 Effects of water treatments, N and P additions on P concentration of tops 197

37 Effects of water treatments, N and P additions on K concentration of tops 200

38. Effects of water treatments, N and P additions on N concentration of roots 203

39 Effects of water treatments, N and P additions on P concentration of roots 205

40. General differential thermal curve for kandites using a 10C/min heating rate: A-removal of adsorbed water, B-removal of combined water, C-removal of last traces of water or structural rearrangement, D-formation of mullite and/or γ-Al_2O_3 E-formation of cristobalite or rapid formation of mullite 249

INTRODUCTION

Paper for newsprint, books, and other printing purposes is an essential commodity for the advancement of education, science, culture, and industry in any developing nation. However, many developing nations are deficient in paper-making raw materials and must depend on imports either of pulp or paper. Conifers (softwoods) are still the most important source of raw materials for paper and they are principally produced in the cold zone of the northern hemisphere (Table 1). In that zone, the total number of forest species is relatively small. Spruce, fir, pine, and larch form extensive pure stands with uninterrupted cover. The soils on which they grow are podzols, or podzolic with raw humus, and are relatively unsuited for raising agricultural crops. The climate is generally adverse for devastating, pathogenic microorganisms and pests. The transport of timber in the winter is much easier than in tropical areas. Although the growth period is short, lasting for about only four months, the annual increment is still appreciable (2.8-3.6 m^3/ha), and it can probably be increased under improved silvicultural practices (Rousseau 1963).

The second most important pulp wood producing area is the temperate zone of the northern hemisphere, composed of the lands south of the Great Lakes in U.S.A., the Baltic Sea in Europe, and the Caucasus in Asia, extending to northern China and Korea. The temperature is higher than in the boreal area, rainfall is well distributed over the year and the soil is very much appreciated for agricultural uses.

TABLE 1

CLASSIFICATION OF FOREST LANDS

Region	Total	Percent of land area	Forest area per capita	In use			Unexploited
				Conifers	Non-conifers	Total	
	million hectares	%	hectares	---------------	million hectares	----	----------
North America	773	33	3.8	252	148	400	333
U.S.S.R.	836	37	4.1	318	140	458	377
Europe	141	30	0.3	80	55	135	8
Central America	74	27	1.4	4	10	14	60
South America	857	54	7.3	8	68	76	881
Africa	753	25	3.4	2	123	125	628
Asia	520	18	0.3	56	182	238	284
Pacific Area	88	11	8.5	4	16	20	78
Total	4,110	31	1.5	713	752	1,465	2,645

Source: FAO 1962 Estimates of the world's forest resources Unasylva 16 123

Conifers and hardwoods are harvested for pulp and paper production. The share of hardwoods as raw material is steadily increasing and is expected to reach 26% of the total consumption by 1975 (Rousseau 1965).

A third potential pulp wood-producing area is the zone of tropical hardwoods, better known as tropical rain forests. The temperature and humidity is high throughout the year. The forests are multi-storied, with trees attaining 60 m in height. The very high number of divergent species makes them commercially unimportant for the production of pulp and paper. The tropical rain forests are a climax formation and despite their majestic appearance, the mass growth is surprisingly low. It is estimated by Rousseau (1965) to be 0.14 m^3/ha annually for the rain forests in the Amazon basin.

Paper-making from vegetable fibers was invented in China around 100 A.D.; however, the paper industry is still not highly developed in that country. The reason is the non-accessibility of raw materials. This problem could be largely overcome by the practice of tree introduction. In analogy with several agricultural crops such as rubber, tea, quinine, coffee, it is certainly possible to cultivate conifers outside their natural habitat in another geographic area with similar climatic and soil conditions. Up to 1960, for example, 623 400 ha of *Pinus radiata* were in cultivation outside the United States and Mexico as an exotic tree (Scott 1960).

Table 2 shows that the paper industry is concentrated in regions with the highest acreage of conifer forests. Consumption of paper and paper products is highest in regions where they are abundantly produced and in countries with a well developed economy that can pay for imports

TABLE 2

PRODUCTION OF PAPER AND BOARD (1,000 metric tons)

Region	Newsprint			Printing and writing paper			Other paper and board		
	1951	1961	1963	1951	1961	1963	1951	1961	1963
North America	5,858	7,931	7,956	4,492	6,445	7,135	17,339	24,510	26,783
U.S.S.R.	267	493	593	339	726	905	1,084	2,231	2,496
Europe	2,522	4,287	4,378	2,636	5,172	5,849	7,017	14,034	15,672
Latin America	55	180	200	154	301	320	534	1,309	1,477
Africa	-	19	103	29	71	122	37	273	379
Asia	262	1,223	1,517	440	1,404	1,908	1,002	5,990	7,298
Pacific Area	32	190	262	26	70	87	188	453	549
World total	9,097	14,309	14,979	8,087	14,189	15,993	27,191	48,809	54,942

Source: FAO. 1965. Yearbook of Forest Products Statistics. Rome of paper material. Much less is consumed in such continents as Africa and Asia, where there is a scarcity of conifers (Table 3).

World consumption increases steadily, not only because of the rapid population growth, but also because continuous research results in new inventions and new uses for paper (Table 4).

The fiber supply deficit appears to be developing into a world problem. This deficit could partially be met by tree selection and breeding, and management practices such as pest and disease control, site preparation and drainage and the use of chemical fertilizers and herbicides. For some time, perhaps as long as 20 years, manufacturing countries will be able to provide the paper needs of deficient nations. However, increasing domestic demands and the adoption of sustained yield principles on the one hand, and the shortage of foreign currency on the other, will impose limitations on importation of paper by developing nations. It is advisable that these countries work towards independence in their paper supply as soon as possible. Paper is a very expensive necessity and its importation is a real burden for nations with low incomes.

Little wonder that the per capita consumption of paper is forcefully kept low in developing nations, as exemplified by Indonesia. In contrast with the increasing use of paper in most other nations (Table 3), the per capita paper consumption in Indonesia, which was already low, was halved in the decade 1956-1966 and ranked 124th among the 137 nations of the world in 1966 (Table 5). To make matters worse this decrease in consumption took place during the period when literacy rate was boosted from 7% in 1948 to 60% in 1960 and the total school enrollment reached 20.4 million. Indonesian paper production was

TABLE 3

CONSUMPTION OF PAPER AND BOARD (kg per capita)

Region	Newsprint			Printing and writing paper			Other paper and board		
	1951	1961	1963	1951	1961	1963	1951	1961	1963
North America	34.0	35.2	34.2	20.1	31.6	33.6	101.4	116.2	124.4
U.S.S.R.	1.2	2.0	2.3	1.6	3.3	3.6	5.8	10.5	11.4
Europe	5.0	6.6	6.7	5.6	11.2	12.4	16.2	32.4	36.7
Latin America	2.5	3.4	3.1	1.4	1.6	1.7	3.8	6.8	7.4
Africa	0.4	0.6	0.8	0.3	0.7	0.8	1.1	1.8	2.2
Asia	0.3	0.6	1.0	0.4	0.6	0.9	0.8	3.7	4.3
Pacific Area	17.1	24.5	22.8	8.1	8.7	9.5	23.8	34.2	37.7
World total	3.6	4.7	4.7	3.2	4.6	5.0	10.8	16.0	17.2

Source: FAO 1965 Yearbook of Forest Products Statistics. Rome.

TABLE 4

WORLD DEMAND FOR PAPER AND BOARD TO 1980
(1,000,000 metric tons)

Region	1965	1970	1975	1980
World total	97.82	128.13	162.04	205.05
North America	43.80	52.26	61.72	72.02
United States	40.05	46.85	57.48	68.65
Latin America	3.44	4.82	6.72	9.36
Western Europe	24.81	32.50	40.36	46.61
Eastern Europe	3.81	5.30	7.30	8.78
Soviet Union	5.30	8.30	12.45	16.10
Near & Middle East	0.32	0.47	0.68	1.02
Africa	1.18	1.78	2.45	3.53
Japan	7.80	10.80	14.30	18.50
Mainland China	4.42	8.31	10.50	16.01
Rest of Asia	1.76	2.46	3.50	4.80
Oceania	1.23	1.56	1.81	2.33

Source: Wilson, A. W. 1966. Pulp, paper break records again. Pulp & Paper 40(29):8-10.

TABLE 5

CONSUMPTION OF PAPER AND BOARD IN INDONESIA AND THE WORLD (kg per capita)

	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Indonesia	1.69	1.59	1.46	1.81	0.99	0.60	0.66	0.77	0.83	0.91
World average	22.14	22.09	24.68	25.04	25.86	26.67	27.63	28.30	30.13	31.30

Compiled from. Statistical data published in Pulp & Paper vol. 33-41 (1958-1967) static from 1955 to 1960 with an output of approximately 7,000 metric tons annually. It began to increase slowly in 1961 until it reached 18,000 metric tons in 1965 and has not increased since. Only a small fraction of the raw materials is native softwood, while the rest comes from rice straw, bamboo, or imported pulp.

Unfortunately, for tropical countries, Coniferae, in general, and pines, in particular, grow best in cold or temperate climates. As a consequence of this requirement, they can be produced at low elevations in a temperate and cold climate in either the northern or southern hemisphere, but most species survive only at high altitudes in the tropics. Exceptions to this rule are Pinus merkusii, indigenous to southeast Asia, and Pinus caribaea from the West Indies and Central America. The former species occurs at sea level in the Philippines, but at lower latitudes, as in Indonesia, it only grows favorably above the 500 m line (Heeksen 1949). Attempts have been made to cultivate P. merkusii at lower elevations in Java, but it fails to domesticate. Plantation trials in alang-alang (Imperata cylindrica) fields in Kalimantan (Borneo) gave discouraging results, presumably because of poor soil fertility or unsuitable climatic conditions.

In 1931, the former Dutch East Indies Government began planting P. merkusii in the Aek Nauli forests in the Toba Lake district, North Sumatra, at an elevation of 1,100 m. Another plantation was later established near Lembang on the southern slopes of Mount Tangkuban Perahu at the same altitude (Ferguson 1954). P. merkusii grew favorably on these volcanic soils, attaining an annual growth rate of 20 to 30 m^3/ha (Ferguson 1954, Hecking 1950). However, these forests, like the 130,000 ha of natural forests in Acheh and some 20,000 ha of high producing plantations in Java and Sumatra, are practically inaccessible as pulpwood suppliers. Bamboo has been the major source of pulp at low elevations, but apparently bamboo needs better soil conditions than pines.

In order to make the extensive alang-alang area of Kalimantan productive enough to support a pulp and paper industry, a pine species should be selected that can survive the uniform high temperature of an equatorial climate along with the high annual rainfall and poor soils at the low elevation.

According to observations by a number of authors (Streets 1962, Lamb 1966), and tests carried out in several tropical countries, it appears that *P. caribaea* var. *hondurensis*, hereinafter referred to as *P. caribaea*, is a species that meets these conditions. Fortunately this species is not new to Indonesia. Hellinga (1949) reported that in February 1938 the Forest Research Institute in Bogor received some seed from British Honduras, and 450 seedlings were transplanted in the field of which 18 trees remained in 1949. The trees had straight boles and the average height within 10 years was 18.3 m and DBH was 28.7 cm (Table 5).

As shown in Table 5, the height and diameter growth of exotic *P. caribaea* exceeded the average growth of the native *P. merkusii*. It is a matter of regret that no additional information was published on these plantings after 1950. These trials show positively that *P. caribaea* can survive and make good early growth in the hot climate of a tropical lowland in Java. It should be noted that Tjikampek is located at a slightly higher latitude and the soil is probably of higher fertility than the average soil in Kalimantan; consequently

TABLE 6

RESULTS OF TWO PLANTATION TRIALS IN INDONESIA
WITH *P. caribaea* AS COMPARED WITH AVERAGE
GROWTH OF *P. merkusii* (after Bellinga 1949)

Experimental plot	*P. caribaea* Tjikampek (20 m elt)	 Sumberwringin (1,000 m elt)	*P. merkusii* Average site
Age (years)	11	10	10
Upperheight[1] (m)	16.9	15.1	14.5
Number of trees	18	9	–
Average height (m)	18.3	15.1	–
Average DBH (cm)	28.7	31.0	19

[1] Upperheight is defined as the arithmetic mean of the 100 highest trees occurring on one hectare (Beekman 1948).

complementary studies on soil fertility and groundwater level are needed. Plantations established in Guyana (Vinira 1967) and Surinam (Versteegh 1966) show that *P. caribaea* can be cultivated with success in an equatorial lowland on deteriorated soils -- conditions comparable to Kalimantan. Despite these rather favorable results with this species, no studies have been undertaken toward developing a better understanding of the effect of environmental factors on the growth of *P. caribaea* var. *hondurensis*, and on possible methods of overcoming these factors.

This research was undertaken in an effort to determine some soil and climatic requirements of *P. caribaea* as a basis for selecting sites and developing management practices necessary for the establishment of this species in alang-alang plains of Kalimantan as a prime source of pulpwood for Indonesia.

REVIEW OF LITERATURE

Climate

P. caribaea grows in Central America from sea level to an elevation of 700 meters, between 12° and 18° north latitude. It thrives in both tropical and subtropical climates existing at various elevations. The species tolerates a wide range of temperature variations between 7 and 38 C (Hunt 1962).

Table 7 presents the distribution of rainfall over the year in the Atlantic coast side of Central America. Stations 1 and 2 (Corozal and Orange Walk) are located outside the pine ridge and are considered to be too dry for pine. Other stations are in areas where *P. caribaea* is indigenous, and they were included to show that *P. caribaea* requires an annual rainfall greater than 1,900 mm and can tolerate up to 4,000 mm. In the coastal pine belt there is almost no dry month (rainfall lower than 60 mm), except in the vicinity of Belize where the months of March and April are considered dry.

Temperature data from this area are very scarce (Table 8). However, available data show the temperature to be remarkably constant year-round.

Romney (1959) claimed that the overall climate of British Honduras is subtropical. However, this may not be true for the area of the Coastal pines, for it has several rainfall and temperature characteristics inherent to a tropical climate.

TABLE 7

AVERAGE MONTHLY RAINFALL IN SELECTED COASTAL STATIONS IN BRITISH HONDURAS, HONDURAS AND NICARAGUA (mm)

Station	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec	Total
						British Honduras*							
1 Corozal Town	85.0	34.6	25.6	31.0	104.6	171.6	123.7	166.5	201.1	142.4	133.1	110.6	1309.0
2 Orange Walk	82.4	52.8	32.5	33.3	112.6	235.6	180.0	174.1	267.0	132.8	103.8	88.0	1495.2
3 Belize City	88.6	70.1	54.0	64.2	85.2	166.8	145.6	184.7	247.6	236.8	225.3	207.1	1703.4
4 Stann Creek	174.4	106.6	65.4	63.3	146.7	366.6	314.5	294.3	304.6	370.2	320.3	317.0	2955.7
5 Punta Gorda	293.8	146.4	108.6	116.2	316.5	606.3	605.6	578.3	638.4	300.4	290.6	270.9	4201.0
						Honduras**							
6 NW Zone	233.4	115.6	73.7	83.2	136.1	184.0	226.8	168.8	164.0	403.2	466.4	340.2	2641.1
						Nicaragua***							
7 Bluefields	270.0	100.0	72.0	77.0	328.0	482.0	846.0	516.0	321.0	324.0	360.0	368.0	3868.0

* From Romney (1959)

** From Wigo (1958)

*** From FAO (1960).

TABLE 8

AVERAGE MONTHLY TEMPERATURE IN SELECTED COASTAL STATIONS
IN BRITISH HONDURAS AND HONDURAS (° C)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
						British Honduras*							
1 Belize City	23.2	23.5	24.8	26.3	26.8	27.0	27.8	27.0	26.8	25.9	24.1	23.5	25.8
						Honduras**							
2. La Ceiba	23.9	24.9	26.8	29.1	29.0	29.0	28.4	28.1	28.1	26.8	25.5	23.3	27.2

* From Bushong (1961)

**From Luckhoff (1964)

According to Van Steenis (1958), the characteristics of a tropical area are:

1. It conforms to latitudinal delimitation; namely, it must be located between the tropics of Cancer and Capricorn.
2. The mean annual temperature at sea-level is at least 26.3 C and decreases about 0.6 C with each 100 m increase in altitude. However, based on the Thornthwaite T - E formula, a mean annual temperature of 23.6 C is the lower temperature limit of a tropical climate (Blumenstock 1958).
3. The natural vegetation is "forest". Reduction in number of species or individuals per hectare is caused by other factors than climate, primarily soil factors. This applies particularly to the areas occupied by pines in British Honduras, where they occur in almost pure stands.

Employing Holdridge's (1967) world classification of life zones, the natural habitat of *P. caribaea* at low elevations could qualify as "tropical moist forest", and that at altitudes higher than 500 m as "subtropical moist forest" (Budowski 1964).

The air humidity in British Honduras, Honduras and Nicaragua, particularly in the area of the lowland pines, is quite high. The average annual relative humidity in Belize, British Honduras is 88% at 6 o'clock in the morning and 74% at noon. In La Ceiba, Honduras, the average monthly atmospheric humidity runs from 70 to 78% (Wise 1958) and in Managua, Nicaragua, it varies from 70 to 87% (FAO 1950).

Consistent winds blow from the southeast at a velocity of about 10 m.p.h. in the months of February to September (southeast trades). From October to January, northerly or northeasterly winds predominate at a much slower speed of about 5 m.p.h. During the Fall of the year, at irregular intervals of several years, tropical revolving storms develop in the Caribbean Sea, bringing high winds and heavy rains, often deteriorating into hurricanes. Some of the recorded hurricanes are those of September 10, 1931, October 4, 1945, September 7, 1955 ('Janet'), July 15, 1960 ('Abbey'), and October 31, 1961 ('Hattie'). Windspeeds of 'Hattie' reached 150 to 230 m.p.h. and caused widespread destruction of houses and other properties, including pine forests (Wolffsohn 1967).

Geology

The geology of British Honduras is dominated mainly by the ancient Maya Mountains. They were formed by intrusions of molten magma in the Paleozoicum, which on cooling produced rocks of granitic and porphyric nature. These rocks consist mainly of quartz and contain almost none of the essential plant elements, such as potassium, calcium, magnesium, and sulfur, or the micro-nutrients, such as copper, zinc, iron and manganese. All soils in British Honduras are directly or indirectly the weathering products of Maya Mountain rocks.

During its long history, the Maya Mountains have undergone periods of uplifts and leveling. On top of this mountain range, at an elevation of 2,750 - 2,950 m, is a small plateau which is considered a part of the original peneplain.

During Cretaceous times almost all but the northeast corner of this massive block was covered by the sea. During this period, limestone deposits several hundred meters thick were laid down.

In the Miocene period, erosion removed almost all of the limestone on the plateau and also large portions of the limestone mantle-

Streams cut deeply into the limestone, quartzite slates and graywacke, giving way to the formation of gorges up to 300 m deep and to the rise of a serrated ridge running in a crescent shape on the east, west and south side of the plateau. Tops of the ridge reach over 1,200 m and make up the highest peaks of the country (Dixon 1957).

The main watershed bordered by the ridge, drains primarily to the Atlantic coast. Many of these rivers, such as the Belize River, run first to the west towards Peten in Guatemala, but make a curve in a northward direction and deposit sediment in the sea, forming the Northern Plain. The Mopan River intercepts all water of the small streams running to the west and brings the water and its contents northward. The Machiquila is the only river that flows to the west and deposits the Maya Mountain sediment in the proximity of Poptun, leaving, thru weathering, a soil similar to that prevailing in the pine ridge of British Honduras (Dixon 1957).

There has been a continuous change in the coast line of British Honduras. In the early Pleistocene or late Tertiary, all lands within approximately 60 m of the present sea level were under the sea, which reached to the foot of the Maya Mountain on the North and East side. The Northern Plain was part of a gulf-like sea. It gradually filled with debris of the limestone mantle of the Maya Mountains. After removal of this mantle, silt transported by rivers to the sea consisted mainly of acidic materials from the Paleozoicum, which were laid down on top of the chalk beds. Thickness of the sediment grew with time and finally rose above the sea surface. In the Quaternary glaciation period the sea retreated and the shoreline dropped to about the 30 m line. One of the consequences of this event was that some of the sandbanks within the cretaceous bay emerged from the sea and appeared as sandy islands while the mainland coast moved forward. From a pedogenic viewpoint, this was a very important episode, as it was chiefly responsible for the sharp differences between the soil of the northern and southeastern coastal plains. The islands formed a main obstacle for the movement of the Maya Mountain silt to the north, forcing the Belize River to change its course eastward. While the deposition of acidic material in the north stopped, it still continues to the present in the eastern coastal plains. The sea currents moving to the south shifted the accumulated silt to the east side of the Maya Mountains. These sediments, along with those brought directly by rivers draining the Maya watershed, form the parent material of the soils on the eastern lowlands south of Belize.

On the other hand, rivers flowing from the cretaceous limestone area on the Guatemalan border, such as the Rio Hondo and its tributaries, filled the lagoons between the sandy islands and the coast. Parts of these materials were also deposited on the seaward side of the islands through activities of sea currents moving southward. Some 3,000 to 4,000 years ago, a 3 to 6 m drop in the ocean level occurred (Dixon 1957).

The southernmost lowlands originated from similar sediments of acidic rocks overlain by chalky silt.

The igneous and metamorphic rocks and sandy sediments in the Mountain Pine Ridge and that of the coastal area are the parent materials of soils on which P. caribaea var. hondurensis, with its characteristic vegetation cover, grows naturally in British Honduras. However, soils from limestone sediments are more suited for agriculture and hardwood forests.

As reported in the previous discussion the soils of British Honduras are derived from igneous, metamorphic, and sedimentary rocks, which result in a wide variety of properties.

Ower (1928), who studied the geology of British Honduras from 1921-1926, gave the following chief rock formations:

1.	Coral reefs, river alluvium (Pine Ridge sands)	Recent
2.	Old coastal alluvium (Pine Ridge formation)	Post Pliocene
3.	Toledo beds	Miocene
4.	Rio Dulce limestones and marls	Oligocene
5.	Igneous rocks and intrusives	Permo Carboniferous
6.	Slate series	Upper Carboniferous

The Slate series can be sub-divided in the Maya and the Macal series, which along with the igneous rocks, compose the Maya massive. The Maya series are considered to be the oldest, presumably of Paleozoic age and containing undefinable fossils. They are composed mainly of metamorphic rocks, such as graywackes, quartzites, shales, phyllites with some schist and gneiss. They are located along the eastern and southern areas of the Maya Mountains, and some isolated outcrops are found on the Mountain Pine Ridge. The Maya series were intruded by granitic igneous rocks. On weathering and erosion of the granites, sandstone of the Macal series were exposed. They are likely from the upper Pennsylvanian to Middle Permian age.

Most of the northern, and much of the southern lowlands are underlain by limestone, including the western part of the Maya Mountains. It dated back from the Oligocene when almost all of British

Honduras was under the sea. Some of the limestone was metamorphosed into marble. Ower (1928) gave these the name of Cayo series.

The Toledo series are thin bedded shales and sandstones with blue calcareous sandstone, mainly localized in the Toledo District. They are considered to be from the Upper Miocene.

The lowland pines in Guatemala grow on soils as weathering products of quaternary and tertiary sediments (Luckhoff 1964).

The southeastern coast of Honduras and the adjoining northeastern part of Nicaragua are chiefly built on sediments carried by the Rio Coco and Rio Patuca and several others. These rivers rise in the Honduras-Nicaragua border highlands which are composed mainly of limestone, argillites, quartzites and quartz rich sandstone conglomerates (Parsons 1955). The sedimentation started in the Cretaceous-Tertiary era, when all of the Atlantic Coast was under the sea. These rivers must have been tempestuous waterways as evidenced by the gravelly sedimentary materials laid down. These sediments were later reworked by marine action with coarse sands and gravel remaining in the north while finer silt was moved by sea currents to the south. It is likely that the coastline was raised in several stages as in British Honduras, but definite terraces are absent.

Soils

All pine ridge soils in British Honduras have well developed profiles so that they can be classified as zonal soils. The zonal soils in Central America are mainly derived from three processes (Stevens 1964).

1. Calcification in arid to semi-arid climates, characterized by accumulation of calcium carbonates and other basic minerals in the soil.

2. Laterization, which resulted from weathering under the influence of percolating water, gradually hydrolyzed and mobilized much of the basic mineral components (Ca, Mg, K and Na). As a consequence of this process, the pH increased up to around 7. At this pH, Si dissolved, while Al and Fe under the influence of high temperatures oxidized to sesquioxides (Al_2O_3 and Fe_2O_3), which are responsible for the reddish color of the soil.

3. Podzolization, can be considered as a type of laterization. In this process, highly acid water dissolved and removed metallic mineral soil constituents of Fe and Al just beneath the accumulated organic matter (A_1). Silica (SiO_2), that is insoluble under such strongly acidic conditions, remained and gave the soil horizons an ash gray color.

It is very likely that calcification occurs in the Northern Pine Ridge, because of the semi-arid climate. Laterization is possible in the Broken Pine Ridge, where seepage water is close to neutral, because of the mixed nature of the litter. In the coastal pine savannas, the percolating waters are more acid under the influence of pine needles, thus resulting in podzolization.

Romney (1959) grouped the pine soils as Red Yellow Podzolic and soils of the intermittently waterlogged savannas as being closer to Planosols.

Hardy *et al.* (1935) gave descriptions of two soil types of the lowland pines which he listed as, (1) old coastal alluvial (Pine Ridge) soil and (2) coastal alluvial (Beach) soil. Both soils match respectively with that [illegible] Pine Ridge and [illegible] Pine Ridge in this study.

Old coastal alluvial (Pine Ridge) soil.--The surface soil (0-15 cm) is a black or dark brownish grey, harsh, powdery, loose, coarse sand. It is highly acidic (pH 5.3). Its organic matter content is fairly high to high (1.8-4.0%) and exhibits a very high C/N ratio (around 11.5), indicating very incomplete decomposition of plant residues. Nutrients are deficient and the rate of solution very low (15 units). The contents of available phosphates are low (around 10 ppm) and of available potash are medium (around 100 ppm).

The sub-surface soil (15-30 cm) is even sandier, coarser, looser and more acidic than the surface soil. It is also about half as humic, with a high C/N ratio (around 10), and extremely deficient in nutrients. Its color is a uniform yellowish-grey.

The subsoil (30-90 cm) is markedly different from the sub-surface soil. It is broadly mottled with patches of orange and rusty red or oranges on a yellowish or grey ground. It is composed of compacted, harsh, gritty sand, containing some kaolinitic clay. Its reaction is very highly acidic.

Coastal alluvial (Beach) soil.--The soil is entirely non-calcareous, and consists of bleached, grey-white, loose, coarse sand, overlying a grey sandy clay at 1 m with iron stains of yellow, orange and brick red in broad patches.

The loose sandy material exhibits slight variation in color in the different layers. It is highly acid in reaction, and nearly devoid of nutrients. There is a thin black layer of richer humic soil between 90 and 138 cm containing nearly 5% organic matter of very high C/N ratic (about 24). The water table is high (at about 80 cm depth), and the impervious clay subsoil limits downward drainage. It is doubtful whether the deep clay subsoil is common at other places within the alluvial area. The underlying marl has not been reached at this site. A nearby well dug to 20 m traversed only siliceous sand and sandy clay.

Characterizations of the two soils described above are presented in Table 8

Hunt (1962) described the profile of pine ridge soil developed on flat or rolling topography as follows: The topsoil is a shallow loamy sand coloured grey by a small amount of humus, grading down into a leached horizon of whitish or yellowish sand of variable depth, often about 45 cm. The proportion of clay increases more or less sharply with depth and the subsoil is a very compact ochre or red clay. The lower layers are often mottled, indicating impeded drainage. Sometimes this 'mottling' represents a final stage in the disintegration of the granitic parent rock with feldspar phenocryst being broken down to grey clays and the iron bearing minerals to red clays. The soil is acid (pH 4.3-5.3), deficient in available nitrogen and phosphorus, and consequently highly infertile.

Luckhoff (1964) distinguished differences between pine woodland soils in the southern coastal plain, northern coastal plain and the Mountain Pine Ridge.

In the southern coastal plain the surface soils consist of coarse white to greyish-white sand, which is enriched with organic matter The upper horizon is highly permeable but is not more than 15 cm thick below this surface horizon is a yellowish sandy loam which is about

TABLE 6

CHARACTERIZATION OF TWO SOIL TYPES UNDER *P. caribaea* (after Hardy *et al.* 1965)

	Surface 15 cm						Second 15 cm						
Site and location	Texture[1]	pH KCl[2]	Organic matter[3] %	Available P[4] ppm	Available K[5] ppm	Total N[6] %	Texture[1]	pH KCl[2]	Organic matter[3] %	Available P[4] ppm	Available K[5] ppm	Total N[6] %	Notes
Old coastal alluvial soil													
6. Sarawee	light sand	5.7	2.71	11	116	0.24	light sand	5.4	1.79	3	not determined	0.11	not subject to flooding
6 Sarawee	"	5.2	2.70	5	83	0.13	"	6.1	1.30	2	"	0.05	poor natural drainage
7 Groots werk	"	6.0	2.16	3	267	0.11	"	5.1	0.65	2	"	0.04	"
11 Groots werk	sand	6.3	1.62	3	60	0.11	sand	6.3	0.60	4	"	0.05	
Mean		5.3	2.71	5.5	137	0.15		6.2	1.16	2.3		0.06	
Coastal alluvial (beach) soil													
46. Bakers	light sand	5.5	1.63	3	66	0.04	light sand	5.4	0.56	2		0.03	poor natural drainage

[1] Index of texture method

[2] On 1:4 soil-water suspension, with the use of quinhydrone electrode.

[3] Oxidation by H_2SO_4 (conc.) and CrO_3 (chromic acid)

[4] Truog ceruleo-molybdate colorimetric method.

[5] Cobalti-nitrite volumetric method

[6] Kjeldahl method

30 cm thick. It is underlain by poorly drained, light colored sandy clays with red and orange mottling. Below this layer a hardpan is found, which impedes root penetration and also causes severe waterlogging.

The soils of the northern coastal plain have similar characteristics to the southern coastal plain except that they are underlain by soft limestone and marl. These soils are acid, badly leached and infertile.

The Mountain Pine Ridge soils are weathering products of granites. They are mostly deep, well drained sandy clays with a good mixture of coarse quartz grit, gravel and stones. The soils are leached and poor in organic matter, which is generally confined to the upper 5 cm, except in valley bottoms, where more fertile alluvium occurs. Available minerals however, appear to be adequate for tree growth and the soils are capable of supporting good stands of pine. The higher hills are generally composed of shales, quartzites and slates, which give rise to poor, shallow soils on the steeper slopes where erosion is rapid.

Hacock (1962) investigated Savanna Pine Ridge soils in the vicinity of Mango Creek. He described the A horizon as being 30 cm thick and composed of a gray sandy soil with a high percentage of raw humus, giving the soil a dark color. The B horizon is approximately 20 cm thick, composed of yellow crumbly clay with more sand fractions on top than below and showing orange ferruginous mottling. The C horizon is white clay with much red ferruginous mottling tending to concretions.

He noted variations in thickness of the A and B horizons at different localities and related this to site qualities. Pine taproots can penetrate as deep as the B horizon but lateral roots are confined to the A horizon. He observed that the thicker the A horizon, and the more fertility in this horizon the greater the growth rate of the trees. Soils with the thickest A horizon are found along the creek side and are consequently the best sites for the area.

The water table varies throughout the area and is never very low, a water table 65 cm to 120 cm being observed. It is possible that his observations were done in the dry season, therefore the relationship between growth and conditions of drainage was not mentioned in his report.

P. caribaea grows on at least three soil series in Guatemala; these are the Poptun, Jubuco and Semuc series (Simmons, *et al.* (1959). The Poptun soils were developed on limestone at an altitude of 500 m on flat topography and they generally have good drainage. The surface layer of 10 to 15 cm consists of dark brown loamy clay, granular structure, with a high organic matter content. The reaction of the surface soil is medium acid (pH 6.0). The sub-surface soil normally found between 15 and 25 cm deep is a reddish-brown clay with a granular structure containing some hard concretions of 0.2-0.5 cm diameter. It has a pH of about 5.5. A sticky clay containing a high concentration of concretions, with a blocky structure and a pH of about 5.5 is found between 25 and 60 cm. Between 60 and 120 cm, the clay is plastic, pale reddish-brown, with a slightly yellowish or brownish mottling due to iron oxides. It has a pH of about 4.5. The subsoil deeper than 120 cm is a yellow plastic clay, with a mottling similar to the previous layer and with a pH of approximately 4.5.

The Jubuco Series, found near Lake Izabal at an elevation between 60 and 450 m, is underlain by serpentine rich rocks (Simmons *et al.* 1959)

The surface soil is a brown loamy clay only 2 cm thick with a fine granular structure and a pH of about 5.5. The subsoil is about 45 cm thick, plastic, reddish-brown clay with a blocky structure. The parent material is partially decomposed serpentine about 75 cm thick, resting on relatively recent rock formation.

On soils of the Semuc Series where pines grow together with hardwoods, a broken ridge type of soil is found in the Department of Verapaz. It occupies tops of hills in an undulating topography at 600 m elevation. The surface soil is only about 2 cm thick, a friable reddish-brown clay with a very high organic matter content (35%) and granular structure. The sub-surface soil is about 15 cm thick, has somewhat less organic matter (10%) than the surface, and is a reddish-brown clay with a granular to sub-blocky structure and a pH of about 5.5. The subsoil is about 100 cm thick, friable, reddish-brown clay. The structure at the top of the horizon is blocky and well developed but it is weak beneath. The reaction is strongly acid. The underlying bedrock is serpentine or mafic rocks weathering into serpentine.

Descriptions of typical pine ridge soils from Central Honduras are not available. Johannessen (1963) described some of the open upland savanna soils of the interior of Honduras on which pines might grow. He distinguished two types, namely, that developed from sedimentary parent material and that from acidic and basaltic tuffs. In general, these soils have a sandy clay surface layer and the clay content increases with depth.

These soils are classed together with the Mosquitia Pine savannas by Stevens (1964) as podzolic because of the high silica content, while the savanna soils derived from basic igneous rocks and sedimentary rocks are closer to reddish-brown and yellowish-brown latosols.

Parsons (1955) observed that the occurrence of both soft and hard woods in the Mosquitia lowlands of Honduras and Nicaragua is related to soil conditions. Savanna vegetation is supported by siliceous and gravelly soils, often containing a mottled impervious subsoil with iron concretions, while the high forest occurred in the crumb-structured, humic clays of superior water holding capacities. The surface of this soil is light grey, becoming darker under poor drainage conditions. It contains quartz gravels that become more iron stained with depth. The B horizon is not easily penetrated by roots as it contains a high content of mottled gravelly clay with iron concretions also occurring within the top 1.2 to 1.5 m.

Helbig (1959) observed layers of blue-green algae on the soils in the Mosquitia wet savannas. The slimy surface made the area hardly passable.

Pendleton (1945) classified the savanna soils from the Mosquitia coast as old alluvial, characterized by impoverished, light-yellowish very acid lixivium in contrast with the recent alluvial soil ("vega lands"), which occupy the narrow strips along rivers. These better soils are built up by brown, fine sandy loams and silt loam, derived from granitic and calcareous materials and support a type of gallery forest.

Because of the domination of reddish color, Pendleton (1945) and Taylor (1962) called those soils derived from the pleistocene marine sediments, Red-Yellow Latosols, while the low lying stands were on hydromorphic soils. This is in contrast to Stevens (1964) who called them Podzolic, because of the coarse texture of the top soil and the acid reaction throughout the profile.

In the uplands of Nueva Segovia, Nicaragua, *P. caribaea* grows on regosols without well defined horizons. This soil is low in organic matter overlying either tertiary volcanic rocks or rapidly decomposing granite and schist (Denevan 1961). The former has a gravelly surface and reddish-brown, gravelly clay subsoil, and the latter has a dark sandy topsoil overlying a lighter color gravelly loam.

Chemical Properties of Pine Ridge Soils

The soils of the natural habitat of *P. caribaea* are very low in nutrients, especially those supporting a pure pine stand. Soils are often more fertile supporting the broken ridge type of vegetation. The pine ridge soils are derived from siliceous igneous, metamorphic or sedimentary rocks. The abundant rainfall of high intensities brings about continuous leaching. The warm climate, in combination with sparse vegetative cover, accelerate the breakdown of silica minerals, which clog soil pores and threaten stability of the surface soil. Furthermore, periodic wildfires destroy the organic materials in which the absorbed nutrients are accumulated.

The only available analytical data on the chemical properties of soils in British Honduras are those of Hardy *et al.* (1935) given in Table 5. He analyzed soils from 55 profiles to depths of 1.5 m. Five profiles can be considered as natural pine ridge soil, mainly from the coastal area.

In general, the pine ridge soils have the following chemical properties:

1. Highly acidic in reaction with a range from pH 4.0 to 6.0.
2. Dark colored surface soil because of the high content of organic matter.

3. The nitrogen in the top 15 cm can be considered as high.
4. The C/N ratio in both topsoil and subsoil is fairly high (11.5 to 10 respectively), indicating incomplete decomposition of plant residues.
5. The rates of solutes were low (25 mhos x 10^{-6*}), which is an indication of low nutrient supplying capacity of the soil.
6. The "available" P is often below 5 ppm.
7. The "available" K is generally below the medium of 80 ppm.

Within the framework of an overall soil survey in Guatemala by Simmons et al. (1959), many soil series including those where P. caribaea might occur incidentally were analyzed for their chemical properties. Examples of these soils are Poptun clay loam, Jubuco clay and Semuc clay.

The analytical data on these soils are presented in Table 10.

Johannessen (1963) reported that the savanna soils from the interior of Honduras were deficient in P.

Analyses by the University of California of Parsons' soil samples from the Mosquitia pine savannas of Honduras and Nicaragua revealed the following:

1. The soil is in general acid (pH from 5.0 to 6.0).
2. The organic matter content of the surface soil is high (1.67 to 5%).
3. The nitrogen content is about 0.05 to 0.07%.

---

*Extracted by measuring the electrical conductivity, by the Kohlrausch-Wheatstone Bridge method, of a water extract after 7 days standing and subtracting the value for "available nutrients", which was determined by the same method.

TABLE 10

ANALYTICAL DATA OF SOILS OF GUATAMALA ON WHICH *P caribaea* VAR *hondurensis* GRO

(after Simmons *et al* 1983)

Hori-zon no	Horizon limits cm	[illegible]	Moist-ure %	Total N %	Organic carbon %	Total organic matter %	Total CEC meq/100g	Ca meq/100g	Mg meq/100g	Na meq/100g	K meq/100g	H meq/100g	Base sat %	Mn ppm	Fe ppm	
						Poptun clay loam										
1	0-12	-	65 24	0 44	6 1	10 48	34 03	5 23	2.82	0 66	0 07	25.22	25 9			
2	12-17	-	43 52	-	3 2	5.50	-	-	-	-	-	-	-		—	—
3	17-50	-	45 50	0 07	0 8	1 55	13 00	2 23	0 14	0 16	0 30	10 17	21 7		-	-
4	50-120	-	48.53	0.05	0 5	0.86	22 69	1 25	0.00	0 24	0.16	21 02	7.1			
5	120-160	-	52.53	0.03	0.2	0.34	33.07	6 50	1.23	0.70	0 16	25 46	23.0	—	-	-
6	160-165	-	-	-	-	-	-	-	-	-	-	-	-	—	—	-
						Jubuco clay										
1	0-2	6 0	36 0	0 38	6.5	14.79	40 68	4 34	13 18	0 14	0.31	22 90	43.9	162 0	75 3	0 1
2	2-45	5 2	43 4	0 17	2.0	3 44	43.63	1 02	14 00	0 06	0 26	28 27	35.2	48 4	62 3	0 0
3	45-60	5 6	46 3	0 03	0 3	0 52	39 88	0 75	12 64	0 05	0 00	26 41	33 7	36 5	165 8	0 0
4	60-80	7.1	22.5	0.03	0 4	0.60	41 46	0.77	12.63	0 23	0.00	27.66	33.3	17.6	88.6	0 0
5	80-200+	7 5	17 6	0.01	0 2	0 34	27 09	0 61	1 67	0 16	0 00	24 75	10.6	13.4	66.0	1 3

TABLE 10—Continued

Horizon no.	Horizon limits	pH*	Moist. equiv.	Total N	Organic carbon	Total organic matter	Exchangeable cations: Total CEC	Ca	Mg	Na	K	H	Base sat	Mn	Fe	P
			%				me/100g						%	ppm		
						Semne clay										
1.	0-2	5.8	75.2	0.69	15.0	25.71	53.10	14.75	10.30	1.37	0.63	26.45	50.2	15.9	28.4	2.8
2.	2-15	5.6	39.2	0.48	5.8	10.15	28.88	0.70	8.24	0.11	-	18.23	33.6	3.8	82.0	1.1
3.	15-40	6.0	33.3	0.20	2.8	4.80	23.98	2.02	7.40	0.17	-	14.39	40.8	75.5	82.0	0.7
4.	40-100	6.2	38.4	0.08	0.8	1.50	31.68	0.81	2.15	0.09	-	30.83	2.7	40.2	232.5	0.0
5	100 +					Bedrock										

*No explanation was given on analytical methods applied

i. The C/N ratios range from 14.5 to 21.9, showing that decomposition of organic matter may be less rapid than usually claimed for tropical areas (Jenny 1950)

Classification of Soils in British Honduras

British Honduras was the first country in Central America to attempt an orderly classification of soils. According to Hardy *et al* (1935) some soil descriptions were made as early as 1883 by Sir Daniel Morris, followed much later by Ower (1928), Sampson (1928), and Wardlaw (1929).

At the request of the Governor-General of British Honduras, Sir Harold Kittermaster, a team of workers under Hardy, from the Imperial College of Tropical Agriculture in Trinidad, in cooperation with the British Honduras Department of Agriculture and Forestry, undertook a detailed study of soils in 1935. They were interested primarily in soils suitable for grapefruit and banana crops.

In 1940, Charter, with a grant from the Colonial Development Fund, made a reconnaissance study of the soils north of the Maya mountains with special reference to their utilization in Agriculture.

Hardy *et al* (1935) made an intensive analysis of the more important soil types for their physical and chemical properties, and Charter (1940) mapped the distribution of sterile and fertile soils from the viewpoint of the agronomist. Much emphasis has been placed on soils for crops suitable for export while the potentialities for foodcrops and forests have been somewhat neglected.

A Land Use Survey Team, organized by the Research Department of the Colonial Office undertook a survey from 1952 to 1954, covering the whole country. This team, composed of A. C. S. Wright, D. H. Romney,

F. C. Burrell, A. C. Williamson, R. M. Arbuckle, V. E. Vial and W. E. Shanks, was successful in the preparation of the most complete report list of agricultural recommendations, vegetation, and soil maps of any region in Central America.

Hardy _et al._ (1935), Charter (1940), and the Land Use Survey Team (Romney 1959) each had their own classification scheme and one may view this as stages towards perfection. Hardy made a classification based on soil type and using parent material as criterium for differentiating the types.

His classification is summarized as follows.

	A. _Alluvial and Detrital Soils._	_Color of soil_
1.	Beach, Estuarine and Swamp Soils	Fawn-grey.
2.	River Levee Soils	
	(a) Lower Reaches.	Grey-fawn
	(b) Upper Reaches.	Red-brown
3.	Detrital and Hill-wash Soils.	Red-brown
4.	Old Coastal Alluvial (Pine Ridge) Soils	Brown-grey to grey.
	B. _Sedentary Soils_	
	I. _Derived from Non-calcareous Rocks_	
5.	Toledo Sandstone had Mudstone Soils.	Chocolate-sepia.
6.	Granitic Soils.	Brown-red.
7.	Schist and Slate Soils	Brick-red
	II. _Derived from Calcareous Rocks_	
8.	Toledo Limestone and Calcareous Sandstone Soils.	Sepia.
9.	Rio Dulce Soils	
	(a) Marl Soils.	Black.
	(b) Limestone Soils.	Dark red.

According to his description *P. caribaea* grows naturally on type A-d (Old Coastal Alluvial) and on S-(b), which he named Coastal Alluvial (Beach) soil of the pine ridge soil type.

Charter (1940) employed in his classification the following categories: division, group, subgroup, facies, suite and series (Table 11). It shows that *P. caribaea* occurs in both flat and uplands, on impermeable soils with a low lime status. Boom suite has groundwater rich in Ca, supplied by underlying layers.

The Land Use Survey Team considered the pine ridge soils to be in a late stage of maturity and developed from lime-poor parent materials. In the first half of the sequence Yellow Latosolic soils are formed leading in the following stages to the formation of Red-Yellow Podzolic soils. They recognized the following stages of maturity:

I. *Immature.* Slightly leached yellow-brown or light brown clays and sandy clays. Fine to moderate blocky structure.

II. *Late immature.* Slight to moderately leached, strong brown clays or sandy clays. Moderate blocky structures in topsoil, coarse blocky subsoil. Faint reddish color developing in subsoil.

III. *Early semimature.* Similar to II but reddish color in subsoil more pronounced. Weak prismatic structures developing in subsoil.

IV. *Mid-semimature.* Moderately leached dull brown to greyish-brown clays and sandy clays with medium to coarse-cut structures in topsoil. Subsoil is fairly sharply differentiated from topsoil. Subsoil

TABLE 11

SCHEME OF CLASSIFICATION OF SOILS (Charter 1940)

Division (origin and relief)	Group (permeability)	Subgroup (lime status)	Phase (drainage)	Suite*** (profile-structure)	Series*** ([illegible])
I Alluvial (Flatland)	I Permeable	A Low lime	1 Free		
			2 Slow*		
			3 Impeded**		
		B High lime	1 Free		
			2 Slow*		
			3 Impeded**		
	II Impermeable	A Low lime	1 Poor (ext)	Baker	Baker
			2 Good (ext)	Belize	Belize
		B High lime	1 Poor (ext)	Boom	Beaver dam
			2 Good (ext)		

TABLE II--Continued

Division (origin and relief)	Group (permeability)	Subgroup (lime status)	Phase (drainage)	Suite*** (profile-structure)	Series*** (soil age)
	I. Permeable	A. Low lime	1 Free		
		B High lime	1 Free		
II Residual (upland)	II Impermeable	A Low lime	1 Good (ext)	a Croja	Chalile Silk grass Blancaneau
				b Dry creek	Dry creek Masal
		B High lime	2 Good (ext)		

---

*Slow and seasonally impeded drainage

**Perennially impeded drainage

***Names below refer to those suites and series supporting pine vegetation only.

ext = external drainage

color light reddish brown, sandy mottled orange and brown. Moderately well developed prismatic structure.

V. **Late semimature.** Moderate to strongly leached sandy clays and sandy clay loams. Topsoil brownish-gray and with coarse granular structure. Subsoil brown-red and compact. Moderate to strong, light red and yellowish-grey mottling. Strong prismatic or massive structure.

Vi. **Sub-mature.** Similar to V. above but topsoil is showing a fine granular structure. Subsoil very compact and light red strongly mottled pale grey and red with reticulate pattern.

VII. **Mature.** Strongly leached loamy sand or sandy topsoils with very weak granular structure or structureless. Subsoil very compact reddish-yellow or yellow in color with very strong reticulate mottling amounting to thick veins of greyish-white and vermilion clay.

The differences between the latosolic and the podzolic stage are characterized by the appearance of an impervious layer caused by the breakdown of silicates to clay which move with percolating water and clog spaces between soil aggregates. This process is favored by high rainfall, warm temperature, and a flat topography - all of which are found in the coastal pine savannas. This impervious layer plays a very important role in soils belonging to this set. It threatens the stability of the topsoil because of waterlogging. On somewhat sloping lands, the topsoil may erode off and accumulate in the hollows. The Survey Team gave the name of *Puletan* to soils in the ultimate stage of maturity.

The Land Use Survey Team distinguished the soils in suites, subsuites and soil sets. A suite was defined as a group of soils derived from the same type of parent material. It was not clear on what basis subsuites were separated, but it apparently had something to do with topography. Furthermore, no definition was given for a soil set. It was assumed to be the equivalent of "soil type" as defined by Hardy *et al.* (1935) in which differences in texture are used as a means of separation.

Soils of British Honduras are categorized by Romney (1959) in 70 soil sets. A number of these sets support *P. caribaea* vegetation, they are without exception unsuitable for agricultural use because of low fertility and or poor drainage.

In terms of Marbut's genetic classification (Baldwin *et al.* 1938), it is likely that 'pedocals' occur in the most northern part of British Honduras where the climate is semi-arid. The northeastern part of the Northern Pine Ridge may have pedocals, such as "tok loamy sand", where pines grow together with lime loving species. The rest of the pine ridge soils are probably "pedalfers". The Broken Pine Ridge and dry savannas are classified as zonal Latosols. The soils of the Mountain Pine Ridge appear to be Red-Yellow Podzolic and those of the wet savanna in the lowlands probably belong to the Ground Water Podzols.

The Land Use Survey Team distinguished 20 gradations in soil on which *P. caribaea* grow, while Charter (1940) and Hardy *et al.* (1935)

divided these soils into 7 and 3 categories respectively. A comparison among the 3 classification systems is hard to make because of the use of different terminology, definitions, and designations. However, the most recent survey made by the Land Use Survey Team appears to be the most detailed and it is the one used by the author in classifying soils sampled in the present study.

Botanical Characteristics

The earliest description on the occurrence of pines in the coastal area of British Honduras was from Morris who visited the colony in 1883. At that time he realized the importance of this pine, which he named *P. cubensis* as a potential timber producer and which also could be tapped to yield good quality resin or distilled for turpentine and tar. It seemed that he assumed that the pines of British Honduras were allied to those pines in the southern states of America.

P. caribaea was the name given by Morelet in 1851, based on a specimen from the West Indies. However American foresters and botanists also included under this name, the slash pine, growing in the coastal region from North Carolina to Florida and westward to Louisiana (Britton 1908).

P. caribaea from Honduras and Guatemala was recorded by Shaw (1914) and from British Honduras by Standley and Record (1936). As early as 1887, Senecluaze attempted to establish the name *P. hondurensis* for the Caribbean pine from Central America, but he failed because his descriptions were not based on fertile herbarium material.

In 1950, Loock made a study of the pines in British Honduras and Mexico and noticed differences between seed and foliage color of the Honduran pine and that of the U.S.A. slash, leading to his publication of the name *P. hondurensis* Loock. However, no differences were found with respect to the former pines and those occurring in the Bahamas and Cuba, and the name proposed was considered nothing more but synonymous to *P. caribaea*.

Foresters in Florida had for a long time observed differences between seedlings of the slash pine from different sources, which led Little and Dorman (1952) to make an intensive study of this species. They finally decided that the slash pine from southeastern United States was quite different from the Central American slash pine, based primarily on the number of needles in a fascicle and the morphology of the cones and seed. The latter was given the name of *P. caribaea*, while the former was classified as *P. elliottii*. A complete description of the Caribbean pine was given by both authors.

Species growing in isolated habitats and under the influence of other species in the same environments develop in the long run quite different ecotypes.

Barrett and Golfari (1962) proposed the division of the species into 3 subspecies or varieties for 3 ecotypes (Cuba, Bahama, and the Central American mainland), mainly based on the number of needles in a fascicle and the attachment of wings to the seed.

The division of the species into three varieties are as follows:

1. *P. caribaea* Morelet var. *caribaea* (tipica)
2. *P. caribaea* Morelet var. *bahamensis* (nov. var.)
3. *P. caribaea* Morelet var. *hondurensis* (nov. var.)

Luckhoff (1964) gave the following key to distinguish the varieties, which he referred to as "subspecies".

Key to the varieties of P. caribaea

A Needles in fascicles of 2 or 3 (sometimes 4, very rarely 5 in young trees), resin ducts 7 to 9, less frequently 3 to 4, cones small, averaging 5 to 7 cm long, apophyses generally somewhat swollen and raised along radial lines, or raised along a distinct transverse keel, seeds averaging slightly more than 5 mm long, wings articulate, seedlings relatively slow growing, bright green with very early (after 3 to 4 months) formation of secondary needles.
.. P. caribaea Morelet var. bahamensis (Griseb.) Barrett et Golfari

AA Needles in fascicles of 3, rarely 4 or 5 in mature trees and very rarely 2, resin ducts typically 3 to 4 (2-7), cones generally 7 to 10 cm long, apophyses typically with well defined transverse keels, seeds 5.7-6.5 mm long .... B

B Seedling bright green with bushy growth habit and exhibiting very early formation of secondary needles (after 3 to 4 months), seedlings and young trees slow growing, seed wings adnate.
.... P. caribaea Morelet var. caribaea

BB Seedlings slender and glaucous-green, development of secondary needles delayed and only starting after nine months or longer, seedlings and young trees fast growing, seed wings articulate.
.... P. caribaea Morelet var. hondurensis (Seneclauze) Barrett et Golfari.

According to Luckhoff (1964) the 3 varieties are adapted to different soil conditions:

- Var. caribaea, occurring on Isle of Pines and Cuba grow on deep, red lateritic soils and sandy loam to clay soils

b. Var. *bahamensis*, which occurs on the Bahama Islands grows exclusively on porous limestone rock with practically no superficial soil covering.

c. Var. *hondurensis*, from Central America, grows on a variety of soil types but as far as is known always with an acid reaction.

Figure 1 shows the natural distribution of the 3 varieties.

Mycorrhizae

It is generally accepted that all pines are mycotrophic, obtaining part of their nutrients by means of mycorrhizae. The kind of mycorrhiza fungi associated with each is generally specific with the tree species. Therefore, a pine plantation can only succeed in the presence of the proper fungi in the soil. Even in British Honduras where *P. caribaea* is native, some mycorrhiza problems have arisen (d'Silva 1949). It was considered until 1949 that cohune ridge soil was preferred to pine ridge soil in nursery beds. However, it was found that growth of pine seedlings was checked when cohune ridge soil was used due to the absence of mycorrhizal fungi.

Pine ridge soil from British Honduras was imported into Surinam for use in nursery beds. This soil was a source of fungi and is credited for part of the success in the introduction of *P. caribaea* to that colony (Van Suchtelen 1962, Versteegh 1966).

According to Versteegh (1966) the mycorrhizal fungi is a *Psillotus* species. Young (1940) reported that a *Boletus* could also associate with this pine (Mukherji and Tapar 1961). In Puerto Rico, *P. caribaea* nursery beds were successfully infected with soil from a *P. virginiana* stand (Briscoe 1959). It is likely that *P. caribaea* is not obligated to a specific associate, but that two or more fungi may develop mycorrhiza.

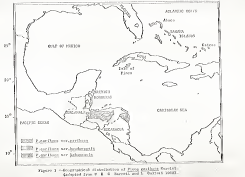


Figure 1 --Geographical distribution of Pinus caribaea Morelet (adapted from W H G Barrett and L Golfari 1962)

Vozzo and Hacskaylo (1961) reported that a number of fungi species might enter into a mycorrhizal association with *P. virginiana*, namely 11 *Boletus*, 5 *Amanita*, 1 *Cenococcum*, 1 *Paxillus* and 1 *Russula* species. Perhaps each of them appears under different sets of environmental factors. Worley and Hacskaylo (1959) wrote that in Virginia pine a black fungus dominates when the soil moisture is low, while a white fungus was active in wet soils.

It is established that mycorrhiza are acidophilic. Each species thrives best at a specific temperature range. Good aeration favors mycorrhiza development. Trees in symbiotic relationship with mycorrhizal fungi respond to high light intensity. A high rate of photosynthesis, and a high rate of carbohydrate production favors the associated fungi. Poor growth of ectotrophic mycorrhiza was observed in soils with high fertility (Kramer and Kozlowski 1960).

Richards and Wilson (1963) used the presence of dichotomous branching on the short roots as an indication of infection.

The relationship between nutrient supply and mycorrhiza development in Caribbean pine was studied by Richards and Wilson (1963). They found that NO_3 N suppressed mycorrhiza development. The lower the N content of the roots, the more mycorrhizal short roots. On the other hand, applications of P increase the number of mycorrhizal roots.

Griffiths (1965) reported from Malaya that mycorrhiza developed on roots of *P. caribaea* by activities of indigenous mycotrophic fungi. He described them as stout (6-8 mm long), white, and to occur in terminal groups showing no apparent dichotomy.

Associated Vegetation

Because of a high requirement for light, *P. caribaea* can only survive in association with an open vegetation, where the young regeneration has access to the needed light, and where the pine is dominating. Such an open vegetation is known in Central America as "savanna", and in this case a pine savanna. Richards (1964) defined savanna as any kind of low growing vegetation dominated by grasses or other herbaceous plants. Schimper (1903) regarded savannas as a climatic climax found in areas with an annual rainfall of 90-180 cm, an effective dry season of 4-5 months and a range in the monthly mean temperature of up to 14 C. This concept does not appear to be entirely valid because many savannas in Central and South America are located in areas with a rain forest climate.

Charter (1940) described savannas as an intermediate stage of deterioration of alluvial soils due to soil impediment. With further impediment of drainage it will be replaced by a treeless grass and sedge savanna. He assumed that the tropical forest is an aging process, characterized by a declining capacity of the soil to support high forest. This concept is faulty because forests, in the absence of disturbing factors, are self-perpetuating and renewable.

Most savannas are not valued for agricultural use because of their low nutrient status and poor physical properties. This leads some ecologists, as Beard (1953), to define savannas as an edaphic climax. This theory does not find general favor because forests are found under the most adverse conditions of soils or climate.

It is claimed that "fires" are mainly responsible for the creation of savannas and because the greater part of fires are man-made, it is conceived that savannas are anthropogenetic. Even soil deterioration by compaction that precedes savanna formation is ascribed to human activities leading to removal of forest cover (Budowski 1956).

The number of species within a savanna is very limited because of poor soil conditions and incidence of fires. The grass cover in the lowlands is not so effective in improving soil structure and fertility as that of temperate zones because of the rapid decomposition of organic matter. The vegetation types listed below as adopted in classification of vegetation by the British Honduras Land Use Survey Team (Romney 1959) are closely related to conditions of soils and are therefore identical with edaphic plant associations.

1. *Broadleaf forests rich in lime loving species*: Mahogany (*Swietenia macrophylla*) and sapote (*Achras sapota* L) are the typical representatives of this type.

2. *Broadleaf forest with occasional lime loving species*: These are evergreen seasonal forests composed of deciduous species.

3. *Transitional broadleaf forests*: These forests have not reached the climax stage, the soil and vegetation show signs of instability. The forest height is lower than the other two types and the canopy is more level. A characteristic species in the shrub layer is the black and white maya (*Miconia* spp).

4. *Shrub land with pine*: This is a transitional type in which the soil is only capable of supporting shrubs, but through the influence of disturbing factors, such as fires, hurricanes, or human activities, pines have a chance to invade. This vegetation is typical of the Broken Pine Ridge.

5. *Pine forest and orchard savanna*: This is the typical pine savanna.

6. Marsh and swamp communities

7. Coastal forestlands

8. Cohune palm (Orbignya cohune) forests. This vegetation area is valued for 'milpas' because the soils are regarded as the most fertile of the lot.

Each vegetation type is subdivided into several groups, which are largely related to available soil moisture. Some variants are distinguished within a group, depending upon minor variation in rainfall and physiognomy. P. caribaea falls in 2 vegetation types, 4 groups, and 7 variants; they are listed in Appendix I.

The term 'low savannas' is used by Standley and Steyermark (1945) to characterize open stands of P. caribaea, Curatella americana, Byrsonima crassifolia. Many species of Gramineae, Cyperaceae, Leguminosae, and Compositae abound. A number of species are really endemic in these savannas in Guatemala.

The associated woody vegetation of the pines in the savannas is mostly brush, with stiff leathery leaves and thick bark as reported by Parsons (1955) for the Mosquitia pine savannas. The most important are Curatella americana, Miconia spp., Byrsonima crassifolia, Calliandra houstoniana, and less commonly Quercus, Crescentia and Mimosa. With regard to the herbaceous plants, the Cyperaceae and the Gramineae are prominent. The Cyperaceae prefer the well drained slopes, especially the Rhynchospora barbata and Bulbostylis paradoxa. Among the bunch grasses most conspicuously represented are: Trachypogon, Andropogon, Paspalum, Aristida and Leptocoryphium. Along the forest margins the grasses are higher and belong to different species, such as Arundinella deppeana, Ischaemum latifolium and Tripsacum laxum. They are considered as transition vegetation between forest and savanna.

Taylor (1962) distinguished 3 layers in a typical pine savanna vegetation:

1. *Groundlayer*, which is frequently very dense 30 to 50 cm high. The species in this layer depend upon the site quality and the frequency of fires. Sedges dominate over grasses on frequently burned sites. The common grasses are *Rhynchospora mexicana*, *Thrasya campylostachya*, *Axonopus blakei*, and *Paspalum humboldtianum*.

2. *Lower tree layer* consists largely of *Byrsonima crassifolia* and *Curatella americana*, more rarely *Clethra hondurensis*, *Quercus oleoides*. The scattered bushes are commonly *Miconia albicans*, *Henriettella seemannii*, *Psidium oerstedianum*, *P. guineense*, *P. rotundifolium*, and *Calliandra houstoniana*.

3. *Tall tree layer* consists of only one species, *P. caribaea*, about 25 m in height, and usually very open but it may be moderately dense.

Taylor (1962) denoted the pine savannas as a fire caused disclimax. He assumed that the natural climax on the site would be a rain forest or a swamp forest. Budowski (1965) included *P. caribaea* in the coastal areas of Central America in the tropical moist forests.

In high quality mature stands there are practically no seedlings, saplings or poles beneath the parent trees, which Lamb (1950) hypothesized was due to a shortage of root room. Nevertheless he occasionally found abundant stands of seedlings, saplings or pole size, which he assumed were established after the destruction of the hardwoods by fires. The FAO Team of foresters for Nicaragua also witnessed the almost total absence of young pole-sized and sapling trees under 100 year old trees. They blamed this incident on repeated burnings.

Parsons (1955) noticed islands of hardwoods within the pine savannas of Mosquitia, which he could not explain on the basis of edaphic differences and considered them as remnants of a xerophytic broadleaved forest which survived the annual fires. Pendleton (1945) thought they were sites of old settlements which had been abandoned by the Mosquitia Indians because the trees got so high that they provided too much shelter to mosquitoes.

P. caribaea occurs in the Mosquitia lowlands mainly on dry sites called the "castales", and they are less frequent in the continuous wet "swamps" (Keikig 1959). Characteristic is the occurrence of several bushy species in the association that have violet flowers, (*Polylongicaulis*, *Tibouchina*, *Miconia*) or fruits ("kiewst")* due to high anthocyan content, which is considered as an indication of nutritional deficiencies, low pH and high Al (Blank 1958). Hardwoods are confined along rivers and creeks, where the soil is more moist and fertile, forming gallery forests.

Human Actions

British Honduras has a long history of human inhabitants. According to Thompson (1954), the greater part of Central America was included in the Maya civilization, which extended over present British Honduras, sections of western El Salvador, the western fringe of Honduras, all of Guatemala (except for some portions along the Pacific coast), all of the Yucatan Peninsula and other parts of southern Mexico.

It was mainly the interior part of British Honduras that was populated by the ancient Maya Indians, and particularly the area of the lime-slope hills and river terraces [illegible], but not regular, seasonal flooding

---

*Scientific name unknown.

Shifting cultivation, involving annual burning of new forest tracts, was a common practice amongst the ancient, as well as, the present day Mayas. Infertile soils were largely avoided for settlement, as it was accepted that neither the ancient nor the modern Mayas practiced agriculture on the unproductive soils of the Mountain Pine Ridge and of the pine lands coastal ellavias.

Burning is done not only to remove trash, but it also improves soil fertility. It promotes mobilization of nutrients that are locked in the plant material. Burning apparently has the same effect as roasting of soils, as widely practiced in many East Asian countries to release soil phosphorus by heat.

There are also archeological remains showing ancient settlements on some of the sterile soils between Belize and Rio Hondo, not far from the shore in the area of the Northern Pine Ridge. It is believed that the people in these settlements did not practice maize-beans-squash agriculture, but lived from seafoods, cocoa, yuca and plantain, analogous to the present day Mosquito Indians in NE Honduras.

The question frequently arises whether man is responsible for the existence of the pine savannas in Central America. One theory is that savannas are solely the result of poor edaphic conditions that do not permit high forests to develop. The other theory holds that man is more or less responsible for the creation or the disappearance of savannas. The third theory, that savannas are products of dry climates, is generally refuted for Central America, as in many other countries where savannas are found, because this is an area with a high annual rainfall.

Beard (1953), who subscribed to the first theory, gave as an example the Aripo savanna in Trinidad, where the vegetation cover did not change after a long period of non-burning.

Perhaps the greater number of authors allege that man-induced fires are the principal agent for sustaining or expanding the savanna acreage. The theory is based on the following:

1. The presence of scorched tree trunks in savannas.
2. The fact that pine savannas are invaded by pioneer hardwood species when fires are kept out during several consecutive years.
3. The occurrence of islands of hardwoods amidst the savanna vegetation.

The extension of savannas could be coupled with expansion of shifting cultivation areas, removal of hardwoods by natural disaster such as hurricanes, and the capacity of fires to move into high forest by nibbling somewhat at its domain.

The properties of a typical pine ridge soil promote combustibility of the plant cover in the dry season, both in the uplands and lowlands. During this period, the storage of water in the soil is very limited because of the sandy texture in the surface soil and impervious layers in the subsoil. The water content of soil, plant, and litter is then at its lowest point making the vegetation easy prey for fires.

Protection of pine lands from fires initially results in promotion of pine regeneration. As tree growth progresses, however, the conditions of the environment change in favor of hardwood competitors that soon settle on the site. These competing trees crowd the habitat and finally lead to suppression and even to elimination of the pines. The findings of remnants of pine trees within some of the rain forests of Honduras and Nicaragua confirm this conclusion.

On the other hand, a high frequency of fires deteriorate the soil to such an extent that it is no longer suitable for pine growth. Extensive treeless areas in Zelaya, Nicaragua, are believed to have been brought about in this way (Lückhoff 1964).

The influence of fires on *P. caribaea* growth is very striking. Due to its tolerance for fires, it is able to compete with hardwoods in the lowlands, where high air temperatures actually encourage hardwood settlement. At high elevations where other pine species prevail, the low temperature inhibits the hardwoods and pines become the sole masters of the site. In the interior of Honduras burning of savannas was motivated as an aid for game hunting, clearing of croplands or to destroy cattle pests (Johannessen 1963).

Parsons (1955) also doubted whether the Mosquitia pine savannas were ever appreciated for agricultural use. The native indians in the vicinity made a living from fishing and hunting and consequently, made little effort to save the pine lands from fires. They burned regularly and traditionally to aid in hunting, to improve grazing, or just as a hobby.

Growth

For a long time it has been noted that the growth rate of *P. caribaea* differs at various localities. The wet savannas was considered as the most unfavorable site, while the highest trees with the best stem form were found in the area of the Kroken Pine Ridge. Apparently poor growth was closely related to conditions of drainage, P deficiency (Craw 1954), and the occurrence of a hardpan (Stevenson 1932) or thickness of A horizon (Hoeneck 1962).

Growth measurements started as early as 1935 in the Brokee Pine Ridge (Stevenson 1936) and according to the Annual Report of 1936 (Stevenson 1937) the average annual girth increment in the sample plots varied from 0.5 cm in old trees to 1.9 cm in young pines. However results of periodical measurements so far have not been released for publication.

Lamb (1969) quoted an estimate of annual growth of 6.3 m^3 per hectare in a fire protected natural pine savanna in Nicaragua and 4.0 m^3 in regularly burned stands. The growing stock was estimated by the F.A.O. Mission at 90-140 m^3 per hectare distributed over 150-175 trees, with a DBH between 30 and 60 cm (FAO 1950).

An inventory by the FAO Survey Team under Haider (1967) reported that natural pine stands in Honduras were much lower than estimates for Nicaragua. It runs in unexploited forests from 11-59 m^3 per hectare and 28-33 m^3 in exploited forests.

P. caribaea has been successfully introduced in many tropical and subtropical countries outside Central America (Streets 1962, Lamb 1968). From data available, only those from Guyana and Surinam are selected for discussion, because these areas have approximately the same climate and soils as Kalimantan. These countries are located not too far from the equator and *P. caribaea* is planted at low elevation.

Table 12 shows clearly that despite unfavorable soil conditions, planted *P. caribaea* shows a diameter, height, and volume growth in Guyana (Vieira 1967) and Surinam (Verstegh 1968) that is not much less than that of *P. merkusii* in Java (Ferguson 1954) on fertile volcanic soil.

TABLE 12

GROWTH OF P. caribaea IN GUYANA AND SURINAM AS COMPARED WITH P. merkusii IN JAVA

Species	Location	Age	DBH over bark Minimum	DBH over bark Mean	DBH over bark Maximum	Height Minimum	Height Mean	Height Maximum	Merchantable volume over bark per hectare Minimum	Merchantable volume over bark per hectare Mean	Merchantable volume over bark per hectare Maximum	Notes
		Year		cm			m			m³		
1 P. caribaea	Guyana	8	3.44	10.23	18.32	4.80	9.37	13.19	29.03	112.15	305.29	White sand
2 P. caribaea	Surinam	9	–	20.10	–	–	16.80	–	–	189.10	–	White sand
3 P. merkusii	Java	10	12.80	19.30	26.50	5.00	14.70	22.00	37.00	125.65	253.00	Young volc
			Mean Annual Increment (M.A.I.)									
1 P. caribaea	Guyana		0.43	1.28	2.35	0.60	1.17	1.83	3.80	14.01	38.16	
2 P. caribaea	Surinam		–	2.23	–	–	1.88	–	–	17.88	–	
3 P. merkusii	Java		1.26	1.93	2.85	0.80	1.47	2.20	3.70	12.50	25.30	

1 Adapted from Vialra (1967)

2 Adapted from Versteegh (1888)

3 Adapted from Ferguson (1954)

Management

Although the forests of British Honduras were the main source of revenue for more than 200 years, it was not until 1922 that the first Conservator of Forests, Mr. C. Hummel, was appointed (Forest Department 1966). He had produced a report on the Forests of British Honduras with suggestions for a far reaching Forest Policy in 1921. Up to 1960, about 525,000 ha were declared forest reserves.

Pine plantings in British Honduras started in 1941 (Stevenson 1942) in the area of the Broken Pine Ridge. Several problems were encountered, such as lack of mycorrhizae and some insect attacks in nurseries, which were finally overcome. In 1947, plantings were expanded to the area of the pine savannas, where new problems were encountered. These were chiefly related to low fertility and high ground water table for extended periods of time (Lamb 1946). These problems were solved by applying superphosphate, improving drainage and planting on ridges. Weeds that threatened to overgrow the seedlings were eradicated by aerial application of herbicides. The results were satisfactory so that plans were made for the conversion of all non-productive pine savannas and other pine woodlands into high producing pulpwood supplying forests as a base for a future pulp and paper industry (Cree 1958).

The technique adopted was that of using 6 month old nursery raised potted seedlings in areas where weed growth was a problem. The savanna grasslands was planted with 2 month old seedlings. The seedlings established themselves successfully provided they were planted in the periods of high rainfall and where excessive weed growth did not compete for available nutrients.

Up to 1960, about 2,500 ha had been planted when it was decided to discontinue many of the silvicultural operations reviewed above. This decision was mainly based on the so-called "Downie Report" (Office of the Premier 1964). Jack Downie, a senior economic adviser in Her Majesty's Treasury, pointed out in a written report that traditional forestry methods were not profitable and therefore spending on forestry should be drastically cut. He reported that a country such as British Honduras, with very limited financial resources, could not afford to invest in long term crops from which the returns are uncertain and possibly uneconomic. Instead, the Government should concentrate on sectors of the economy which promise quicker returns. He pointed out that the Forestry Service should limit its activities to watershed management and erosion control, provide timber to satisfy local needs, and above all, protect pine areas from wildfires. It was aimed that stocking of pine forests would improve by protection of natural regeneration from fire. The Mountain Pine Ridge forests were controlled on a sustained yield basis, with a timber producing rotation of 40 years. On the coastal plains, a pulpwood rotation of 15 years was scheduled.

Utilization

Honduran pine, included in the yellow pine group (Loock 1950) and classified as pitch pine, yields a fairly heavy timber (s.g. 0.55-0.60 at 15% moisture content). Its wood properties and uses were excellently reviewed by Longwood (1962).

The annual volume of P. caribaea timber exploited in British Honduras has been at a rate of 22,400 m^3 (800,000 cu ft), of which more than half has been exported (Anonymous 1962). The official figures on timber exports from British Honduras are given in Table 13. Pine forests cover 1,000,000 ha (Lockley 1964) in Honduras and make up the bulk of

TABLE 13

TIMBER EXPORTS FROM BRITISH HONDURAS IN 1962 AND 1963
(compiled from British Honduras 1965)

Commodity	1962		1963	
	Quantity m^3	Value BH$	Quantity m^3	Value BH$
Mahogany logs	937	30,538	2,847	34,113
Mahogany lumber	156,414	1,577,072	190,714	2,180,419
Cedar logs	44	1,454	2,877	21,777
Cedar lumber	11,369	100,180	21,179	199,819
Pine lumber	19,989	127,507	40,722	300,524

lumber exports in that country (Table 14). Export of pine lumber from Nicaragua is also important (Table 15).

Like slash pine in Florida, also resin can be tapped from Caribbean pine trees. The properties and composition of the turpentine were found to be satisfactory according to Mirov (1961). However, resin and turpentine have been exported only from Honduras (Table 16). A naval stores operation was installed in Puerto Cabezas, Nicaragua, in 1964 and the turpentine produced was sold to chemical plants within the country (Leckley 1964). Hercules Powder Company also started a naval stores operation in Mango Creek, British Honduras, but had to stop the project within 2 or 3 years because of a shortage of raw materials.

More recently, the feasibility of *P. caribaea* var. *hondurensis* as a source of pulpwood has been studied by FAO. No pulp and paper mill has as yet located in any of the 3 countries (British Honduras, Honduras and Nicaragua) where this species is indigenous.

Establishment of a pulp and paper operation in British Honduras appeared unfavorable at the time of a study made in 1957. The most important reasons given by LeCacheux (1957) were:

1. Some 88% of the pine forests is assigned to supply logs to 23 mills in operation, and only 12% of the growing stock is available for an eventual paper industry. This is not adequate wood for a mill designed to produce a minimum of 100,000 ton/year.
2. The local paper market will be too small for the next 10 years to absorb the production.
3. Most of the present forests are "under stocked", because of over exploitation and forest fires. A great number of the planted trees have not yet attained pulpwood size.

TABLE 14

HONDURAS LUMBER EXPORTS - 1959-1962 (from Leckley 1964)

Kind of lumber	1959	1960	1961	1962
Cedar logs	$ -[1]	$ 8,739[1]	$ 9,069[1]	$ 14,498[1]
Sawn cedar	39,753	26,751	36,114	71,784
Mahogany & walnut logs	3,073	90,012	225,303	93,329
Mahogany lumber	27,257	21,105	35,931	54,729
Other non-coniferous logs	11,879	27,943	4,219	37,729
Other non-coniferous species, sawn	74,885	30,032	37,787	101,462
Pine logs	2,333,890	1,759,192	1,877,985	1,510,760
Sawn pine & pitch pine	5,707,633	9,219,402	5,324,568	5,050,779
Other logs, miscellaneous	13,068	4,301	91,997	18,391
Railroad ties, sawn	109,688	91,524	43,925	189,767
Totals	$8,217,016	[illegible],217,018	$7,482,338	$7,120,330

[1] Values in U.S. Dollars.

TABLE 18

LOG AND LUMBER EXPORTS OF NICARAGUA
(from Lackley 1964)

	1960		1961	
	Lumber	Logs	Lumber	Logs
Pine	$2,108,000[1]	$ -	$1,166,000[1]	$ -
Mahogany	661,000	238,000[1]	692,000	345,000[1]
Cedar	301,000	188,000	424,000	195,000
Guayacan	-	77,000	3,000	78,000
Others	18,000	-	10,000	3,000
Total	$3,592,000		$3,413,000	

[1] Values in U S dollars

TABLE 16

EXPORTS OF ROSIN AND TURPENTINE FROM HONDURAS 1957-1965
(compiled from Naval Stores Review 1958-1966)

Year	Rosin 1,000 kg	Turpentine 1,000 litres
1957	625.6	75.7
1958	730.7	124.6
1959	678.1	177.6
1960	680.6	219.5
1961	724.6	248.0
1962	678.5	227.1
1963	543.6	106.0
1964	453.0	75.7
1965	1,264.5	291.4

In the Republic of Honduras the prospects for a pulp and paper industry are much better. A large part of the pine forests have been surveyed and mapped by a FAO team (Snider 1967). A pulp and paper mill, with a capacity between 170-190,000 tons/year is planned for Rio Mame. It will be an integrated enterprise, producing pulp, lumber, turpentine and tall oil (Goethals 1967).

P. caribaea has been tested for its pulping quality by the Forest Product Laboratory in Wisconsin, using samples from British Honduras (Schafer and Chidester 1961). The findings indicated that sulfate pulping produced kraft pulp as good as slash pine. For white paper production it should be mixed with other pulps. *P. caribaea* has about the same grinding properties as Southern pines; ground wood is suitable for newsprint.

However, tests made by the South African Pulp and Paper Industries in 1960 with samples taken from young trees planted in South Africa gave the impression that wood from young pines was unsuitable for chemical pulp (Luckhoff 1964).

Recently, pulping properties of *P. caribaea* were examined in the Tropical Products Laboratory, Ministry of Overseas Development, London, by a team directed by Chittenden *et al.* (1967). It turned out that the sample of *P. caribaea* from Fiji had better pulping qualities than a sample from the Mountain Pine Ridge in British Honduras.

MATERIALS AND METHODS

The research conducted under this project can be conveniently divided into the following two phases

1. Studies on soil properties and tree growth in British Honduras.
2. Greenhouse experiment involving fertilizer application and soil water level

Studies on Soil Properties and Tree Growth in British Honduras

Sampling Techniques

Field samples for the investigation were taken from 14 forest sites. The choice of the sites was based on physiographic feature and apparent growth rate of *P. caribaea* within each physiographic unit.

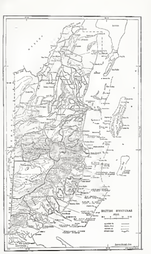
Three physiographic units were distinguished in the main area of study in southern British Honduras (Figure 2).

1. Savanna Pine Ridge (natural stands and plantations of *P. caribaea*)
2. Broken Pine Ridge (plantations)
3. Melinda Coastal Pine Ridge (natural stands).

Cursory examinations were also made in two other pine ridges. These were Mountain Pine Ridge and Northern Pine Ridge, where climate and soils are different from the above three pine communities.

Three site quality ratings were developed corresponding to high, medium and poor productivity. These ratings were based on tree appearance, vigor and stand density. In the absence of a more objective method of measuring tree growth rate, this part of the study was necessarily somewhat subjective.

Figure 2.--Map of British Honduras showing the location of the pine ridges. I-Savanna Pine Ridge, II-Broken Pine Ridge, III-Melinda Cumatal Pine Ridge, IV-Mountain Pine Ridge, V-Northern Pine Ridge.


BRITISH HONDURAS

Three soil sampling pits were dug in each physiographic area; one in the vicinity of each tree from which measurements were taken. Two additional pits were dug, one in the Mountain Pine Ridge and the other in Northern Pine Ridge close to the most northern limit of distribution of the species. The sites in all instances were on soils that, according to available information, had never been fertilized. An attempt was made to dig the pits to a depth of 1.2 meters, but in some places it was impossible to attain this depth because of a high ground water table. Unfortunately, it was necessary to carry out this field phase during the rainy season, at which time the undesirable physical properties of the soils were very pronounced. With the workers and equipment available, it was possible to dig pits and sample only two sites per day in the fine textured soils.

Soil horizons were identified and their thickness was measured and recorded. Three core samples of 59 ml volume each were obtained from every horizon by driving an open brass cylinder horizontally into the wall until it was completely filled. Samples of each horizon were stored in separate cloth bags.

Field notes were taken on the nature and amount of surrounding vegetation, on the relief, elevation, degree of erosion, and stoniness of the terrain, on external and internal drainage, occurrence of mottling, depth phase, texture, structure, consistence and color of the soil.

Height and diameter measurements were taken from three trees in the vicinity of each profile pit. Current-year needle samples were collected from the top one-third of the crowns of the three trees. A rope was suspended from the top of the tree in taking tree height measurements. Height of trees lower than 5 m were taken with a rod. Diameters at breast height (DBH) were measured with a steel tape

Approximately 300 kg of surface soil from the Coastal Pine Ridge near Melinda (Profile XII), taken to a depth of 30 cm, was collected after removal of surface debris. This soil, from a relatively poor quality site, was shipped to Gainesville, Florida for use in a greenhouse experiment.

Laboratory Analyses

Physical analyses.--Soil samples were stored in a dry environment until ready for shipment. Shortly before shipment by air from Belize, all bagged samples were placed inside a local bakery, where they were allowed to dry further.

On arrival in Miami, Florida, all samples were fumigated by the USDA Plant Quarantine Station to conform with regulations. Customs agents forwarded the soil to Gainesville after fumigation.

Oven-dry (105 C) weight of soil samples was ascertained by the gravimetric method. Bulk density was determined by the method of Blake (1965), using the dry weights of the core samples.

Prior to laboratory analyses, the soil was crushed and ground to pass through a 2 mm aluminum sieve, and stored in open paper bags where it was allowed to air dry. Soil color was determined on moistened samples with the aid of the standard Munsell color chart. The pycnometer method was used in determination of particle density, following procedures described by Blake (1965a).

Pore space (P) expressed in percent by volume, was calculated from particle density (PD) and bulk density (BD) of soil material as follows:

$$P \ (\%) = \frac{PD - BD}{PD} \times 100$$

Field capacity moisture was assumed to be that moisture retained in the soil at 1/3 bar pressure. Wilting percentage moisture was that moisture retained at 15 bars pressure, as determined with the porous ceramic plate apparatus discussed by Richards (1965).

Particle size distribution was measured by the hydrometer method of Bouyoucos (1962). The percents of sand, silt and clay were calculated and the sand fraction was subdivided into very coarse, coarse, medium, fine and very fine sand portions using U.S. Standard sieves.

After the second hydrometer reading in the determination of particle size distribution, the suspension was siphoned off to the depth of the hydrometer to be used for clay mineral determination. In this procedure, 5 g of $CaCl_2$ were added to precipitate the clay. The process was hastened by heating to 80 C on a hot plate. The clear supernatant was discarded and the sediment transferred to 100-ml centrifuge tubes. The clear supernatant resulting from centrifugation at 1,500 to 2,000 rpm was also discarded. Organic material on the clay was oxidized with H_2O_2. After addition of 50 ml of 0.01 M $CaCl_2$, a second centrifugation was necessary to remove dispersant, excess $CaCl_2$, and other salts. Following removal of the supernatant, the clay was spread on glassine paper and dried at room temperature and then at 40 C for 24 hours before differential thermal analysis (DTA).

Clay minerals were identified by DTA, using the Deltatherm DTA apparatus and following procedures stipulated by Fiskell and Carlisle (1964). Interpretation of curves produced by the analysis was made on the basis of the location of the endo- and exo-thermic peaks guided by data compiled by Jackson (1956). The relative distribution of the various minerals was assessed by calculation of the peak areas.

Soil used in the greenhouse experiments was also analyzed by X-ray diffraction using the method described by Whittig (1965). X-ray diffraction on Mg and K saturated samples were obtained by Cu radiation with Ni filter, using a current of 10 ma

Chemical analysis.--The following chemical properties of the British Honduras pine ridge soils were measured: hydrogen ion concentration (pH), cation exchange capacity (CEC), total N, and extractable P, K, Ca, Mg, Na, Fe, Al, and Mn.

The pH was ascertained potentiometrically with a Corning pH meter, employing a glass and calomel reference electrode. The measurements were made in suspensions with distilled water and with N KCl, using a soil:solution ratio of 1:2 in both instances.

Cation-exchange capacity (CEC) was determined by NH_4- saturation (Chapman 1965). Exchangeable bases were leached under suction with a neutral $\underline{N}$ NH_4OAc solution. Ammonium not adsorbed on the exchange complex was removed by EtOH (95%). This was followed by replacement of NH_4 by excess Na. The NH_4 in the leachate was then distilled into 4% boric acid and titrated with 0.1 $\underline{N}$ HCl.

A modified macro-Kjeldahl (A.O.A.C. 1945) was employed in the determination of total N using 10-g soil samples.

For the determination of extractable nutrients, 5-g soil samples were extracted with 25 ml of $\underline{N}$ NH_4OAc solution, buffered at pH 4.8, after shaking for 30 minutes.

✓ Extractable P was determined in the filtrate by the chlorostannous molybdenum blue method as outlined by Jackson (1958), using the Bausch and Lomb Spectronic 20 Colorimeter. Extractable K was measured by flame emission with the Beckman Model B Flame Spectrophotometer, using an acetylene-oxygen assembly and employing a wavelength of 765 mu. This instrument was also used for determinations of extractable Ca at wavelength 622 mu, and Na at wavelength 589 mu.

The Beckman Model DU Flame Spectrophotometer was used to ascertain the level of Mg in the extract, employing a wavelength of 285.2 mu.

Concentration of extractable Fe, Al, and Mn were determined with the Model 303 Perkin-Elmer Atomic Absorption Spectrophotometer at wavelengths of 2,493, 3,090, and 2,790 A°, respectively.

Organic matter was determined by wet oxidation with chromic acid, according to the method of Walkley and Black (1934).

Climatic and Environmental Data

The British Honduras Forestry Department keeps an intensive record of meteorological data as an aid in silvicultural operations and fire control. Records on rainfall, temperature, wind speed and direction were kept up-to-date for each Forest Division (Savanna, Melinda and Augustin). Permission was granted to summarize records on rainfall and temperature for use in this dissertation. Rainfall data of Belize Airport and Maskall were obtained from the British Honduras Department of Agriculture.

C. W. Thornthwaite Associates of the Laboratory of Climatology in Elmer, N. J., assisted in computation of the water balance for several stations located within and outside pine ridge area.

Greenhouse Experiment Involving Fertilizer Applications and Soil Water Level

Soil

A greenhouse experiment was conducted to supplement field data relating soil conditions to tree growth, using soil from the Melinda Coastal Pine Ridge. Drying, transportation by air, and fumigation by USDA Plant Quarantine Station were assumed to have no significant effect on soil physical and chemical properties. On arrival in Gainesville, the soil was again dried, sieved, and thoroughly mixed, with care taken against contamination.

The soil was weighed into 56 plastic pots, 2.7 kg soil per pot. The pots were filled to within 4 cm of the brim. Holes at the bottom were filled with glass wool, allowing free movement of water but preventing loss of soil. Samples of the soil were taken for characterization purposes before application of treatments. Shortly before harvest, soil samples were taken again from each pot, using a soil probe. Physical and chemical analyses were carried out on these samples following the methods described for profile samples. These analyses provided information on chemical changes in the soil as a result of tree growth and treatments. Physical and chemical properties of soil used in pots are tabulated in Table 17. Figure 3 represents diffractograms of clay separates saturated with Mg and K.

Plant Material

Seeds of Caribbean pine of British Honduras were used in this experiment. Before germination, seeds were covered with tapwater and cooled in the refrigerator for six hours followed by immersion in 1% H_2O_2 solution for 24 hours at room temperature (Carter and Jones 1962). Seeds were not graded as to size or weight, because of the small quantity of seed available.

Seeds were initially sown directly in pots, but because germination was poor, it was decided to germinate the seed between two layers of moistened cheesecloth. Two days after germination, four seedlings were transferred into each pot. The pots were watered every day with 50 ml of distilled water. Some further transplanting was necessary to replace plants killed by a damping-off fungus.

Seedlings were allowed to grow in pots for a month before application of first treatments.

TABLE 17

SOME PHYSICAL AND CHEMICAL PROPERTIES OF SOIL USED IN GREENHOUSE EXPERIMENT WITH *P. caribaea* SEEDLINGS

Particle size distribution											*N* NH_4OAc (pH 4.8) Extractable nutrients							
Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Total sand	Clay	Silt	Total N	pH H_2O	CEC	P	K	Ca	Mg	Na	Fe	Al	Mn
----------			percent				----------			meq/ 100 g	----------			ppm			----------	
1.3	7.4	17.3	30.6	18.2	75.4	7.2	17.4	0.03	5.00	2.03	8	42	108	24	110	35	56	[illegible]

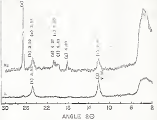


Figure 3.—X-ray diffractograms of Mg and K saturated clay fractions of soil used in greenhouse experiment. a = Quartz, b = Montmorillonite, c h, i, j = Metahalloysite, Kaolinite, d = Gypsum, e = Gibbsite, f = Metahalloysite, g = Chlorite

Treatments

The experiment was set up as a split-plot factorial, replicated in three randomized blocks. It was designed to simulate and test some conditions prevailing in the field. The biggest silvicultural problem in British Honduras appeared to be the establishment of natural or plantation forests in the lowland pine ridge because of a high water table during prolonged periods and deficiencies of certain nutrients.

For the main-plot treatments, one-half of the pots were assigned to reflect well-drained soils and the other half to simulate wet soil conditions. For the latter treatment pots were inserted in larger plastic containers and filled with water to within 5 cm of the soil surface.

The sub-plot treatments consisted of all combinations of four levels of N (0, 125, 250 and 500 ppm) and four levels of P (0, 62.5, 125 and 250 ppm). Fertilizer materials were C. P. grade $NaH_2PO_4 \cdot H_2O$ and granular NH_4NO_3, respectively. Chemicals were supplied as solutions in split applications during four consecutive days. One month after fertilization the water saturation treatments were applied to one-half of the pots.

Pots simulating well-drained conditions were watered as needed to insure good growth while the water level in the saturated pots was kept constant by daily additions.

Measurements

Heights of seedlings were measured shortly before subplot treatments were made and again at harvest, approximately six months later. Diameters were taken only at the end of the experiment, using a micro-caliper. At harvest, seedlings were cautiously separated from the soil with the help of a water spray to minimize the loss of parts of the root system. The seedlings were separated into tops and roots and placed in individual bags. The samples were dried for 24 hours and weighed. Estimations of mycorrhizae development were made with the use of a 15x binocular microscope.

Plant Analyses

Dried plant samples for elemental analysis were ground in a stainless steel Wiley Mill, using a 20-mesh screen, mixed, and stored in glass containers. Dry ashing of plant tissue was conducted at 500 C as recommended by Jackson (1958).

The analytical methods for determining total N, P, K, Mg, Ca and Na in plants were similar to those described for soils.

Concentrations of Cu, Fe and Zn of tops were determined with the Model 303 Perkin-Elmer Atomic Absorption Spectrophotometer at wavelengths of 3,250, 2,483, and 2,140 A°, respectively.

RESULTS AND DISCUSSION

Environmental Measurements

Preliminary Site Evaluation

Native conditions

The general appearance and vigor of trees is one of the best indicators for evaluating the suitability of a particular soil for tree growth. Cree (1956) used this criterion when he grouped the coastal pine forests of southern British Honduras into the following types, closely related to declining site quality.

1.	Broken Pine Ridge covering	26,586 ha
2.	Dense pine woodland covering	7,323 ha
3.	Medium dense pine woodland	19,355 ha
4.	Sparse pine woodland covering	19,478 ha
	Total	72,742 ha

The Broken Pine Ridge is a mixture of low hardwoods and pine, forming a stand with a closed canopy. The pines grow in even-aged patches. A pure pine forest results after removal of the hardwoods. This type produces the best quality pines with tall fast growing trees of good form. The soil is considered as the best pine ridge soil.

A dense pine natural regeneration develops on well drained pine ridge sites generally with an open grass covered floor. Conversion of this type to productive pine forests could be performed by retention of at least eight seed trees per hectare, removal of undesirable trees, and providing fire protection.

The medium dense pine woodlands require more efforts for their transition into productive forests, operational activities related to cultivation, sowing or plowing are necessary

The sparse pine woodlands and savannas consist of poorly stocked open grassy vegetation in which the trees are often stunted, grading down into badly drained savannas, where conditions may be so extreme that pine trees are practically absent Most of the trees on these savannas are over-aged, as indicated by the flat shape of their crown. Fires have destroyed all the intermediate age classes, resulting in a complete absence of pine regeneration in the open savannas. McWilliam and Richards (1954) estimated that the average age of the trees is more than 60 years

Site classification as a basis for soil sampling

Adoption of a general classification applicable for all sites, where P. caribaea grows naturally in British Honduras is not practical because of large differences in climatic and soil factors between the various physiognomical units, resulting in different vigor in growth. Therefore, within each physiognomical unit Savanna Pine Ridge (natural stand and plantation), Broken Pine Ridge (plantation), and Melinda Coastal Pine Ridge (natural stand), three classes are distinguished: medium, high, and low. One profile was dug and sampled within each apparent site class It was nearly impossible to determine the exact age of natural stands as a basis of comparison of relative growth of trees among sites Choice of profile pit sites was therefore based on rather subjective methods, taking into consideration impression on density of stands, vigor and size of trees (Table 18).

The height of the water table is a good indicator of site pro-

TABLE 18

SOME ENVIRONMENTAL OBSERVATIONS NEAR SOIL PROFILE PITS

Profile no.	Physiography	Apparent site productivity	Relief	Depth water table	Drainage[1] class	Stand age	Tree measurements					
							Height			DBH		
							1	2	3	1	2	3
				cm		Year	m			cm		
I	Pine savanna	Low	Flat	22	0	>60	4.8	4.8	3.7	8.9	8.8	8.4
II	" "	Medium	Flat	45	1	>80	4.3	1.7	3.2	7.8	2.5	7.4
III	" "	High	Normal	60	2	>80	7.9	2.8	7.8	13.7	4.8	10.4
IV	Pine plantation within savanna	High	Normal	70	3	14	7.0	3.7	6.1	12.7	8.8	3.1
V	"	Medium	Normal	80	3	14	3.5	3.1	3.8	7.1	7.4	8.8
VI	"	Low	Flat	80	1	15	2.8	2.4	4.3	4.8	5.3	4.3
VII	Pine plantation in Broken Pine Ridge	High	Excessive	100	3	15	14.0	14.6	13.8	21.8	23.8	26.7
VIII	" "	Medium	Excessive	120	4	15	14.9	13.1	14.3	22.7	22.7	22.7
IX	" "	Low	Subnormal	70	1	23	14.3	11.8	14.3	22.7	20.2	26.5
X	Mollndo Coastal Pine Ridge	High	Normal	80	4	>80	12.8	8.5	11.9	17.0	13.8	13.8

TABLE 18--Continued

Profile no	Physiography	Apparent site productivity	Relief	Depth water table	Drainage[1] class	Stand age	Tree measurements					
							Height			DBH		
							1	2	3	1	2	3
				cm		Year	m			cm		
XI	Melinda Coastal Pine Ridge	Medium	Subnormal	70	3	>60	10.1	10.7	8.8	20.2	22.7	13.5
XII	" "	Low	Flat	30	0	>60	5.2	4.3	4.8	10.5	7.3	8.9
XIII	Mountain Pine Ridge	Medium	Excessive	200	5	>60	18.2	12.8	14.8	23.5	20.8	28.1
XIV	Northern Pine Ridge	Medium	Flat	40	3	-	-	-	-	-	-	-

---

[1] As adapted by USDA Soil Survey Staff 1951. Soil Survey Manual USDA Handbook No. 18, Washington, D C

[illegible], especially in sites with a flat topography. High water tables, not lower than 20 to 30 cm in the rainy season, were associated with low producing sites. The prevalence of impeded drainage could easily be identified in the field by the presence of red orange ferruginous mottling in the profile tending to form iron concretions. Black mottlings, familiar to those in rice paddy soil profiles, were not observed, probably because of low soil Mn contents. Silica, Fe and clay were apparently the most important cementing agents in the subsoils.

Level topography was mainly responsible for unfavorable external drainage. It was noted during the survey that a rain lasting for 1 or 2 hours would inundate the savannas on flat and concave topography (Figure 4). Since 8 of the 12 months were wet, a high water table prevailed most of the time on such soils. Tree growth was adversely affected because of the insufficient depth of utilizable soil, reflected in shallow root systems.

Soil

Morphological soil factors

Fourteen sites were sampled by digging profile pits (Table 18). However, in the coastal lowland it was impossible to dig profile pits down to the parent material because of the high water table during the sampling period. All profiles showed distinct horizon differentiation.

Soils under coastal pines developed mainly over materials of relatively recent marine or river alluvial origin. Those in the Mountain Pine Ridge were residual and were derived *in situ* from the underlying rock.

The pine vegetation in British Honduras appeared in three physi-

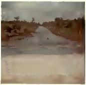


Figure 4.--Poor soil drainage in the Savanna Pine Ridge is indicated by standing water on this fire break after an hours rain.

ognomical units, reflecting soil site qualities in declining order, namely, (a) forest, (b) woodland, and (c) scrub. Using Heyligers' (1963) definitions for these terms, poor stands in the Savanna Pine Ridge and Melinda Coastal Pine Ridge with trees averaging less than 6 m tall should be classified as scrub. The Northern Pine Ridge and best sites of the Savanna Pine Ridge and Melinda Coastal Pine Ridge where trees apparently attain a height of 6 to 15 m are woodlands. Only the pine stands in the Broken Pine Ridge and Mountain Pine Ridge deserve to be called forest, because many trees in these areas are higher than 15 m and have a distinct bole.

The soils sustaining *P. caribaea* in the different pine ridges differ so much that they should be classified in different Soil Orders (7th Approximation). It appears that the following Soil Orders prevail in the *P. caribaea* area of British Honduras:

Savanna Pine Ridge	Ultisols
Broken Pine Ridge	Oxisols
Melinda Coastal Pine Ridge	Entisols, Ultisols
Mountain Pine Ridge	Ultisols
Northern Pine Ridge	Alfisols

Detailed descriptions of morphological properties of these soils are given in Appendix II.

The F layer is typically missing in all profiles because of rapid rates of decomposition and mineralization of organic materials under the influence of high rainfall and temperature.

Savanna Pine Ridge (Profile I - VI).--The A_1 layer is generally sandy, high in organic matter, composed mainly of raw humus and is very strongly acid. The underlying layer is also sandy, but less dark, probably due to leaching. Structure and consistence of the A layer are favorable for root penetration.

The B horizon has streaks of orange and red mottling, occasionally also with gleization, which are signs of impeded drainage conditions. The color varies from yellowish at the top to brown in the subsoil. There were indications that Fe was reduced and accumulated in deeper layers. The amount of clay increased with depth. The soil structure also changed with depth, from granular to angular blocky and prismatic and finally became structureless or massive, and impervious, with the characteristics of a clay pan. Depth of this massive layer determines the range of fluctuation of the water table and thus rooting space. A slight elevation in topography means a corresponding lowering of water table and a considerable increase of root space. On such microsites, trees are observed to grow better. A good drainage system would have the same effect but would probably not be effective during the months of the highest rainfall because of the extremely flat topography.

On the poorly drained sites, trees are not higher than 5 m with a maximum DBH outside bark of 10 cm; on the better sites they attain 8 m height and 15 cm DBH within 10 years (Table 18, Figures 5, 6 and 7). Optimum growth is observed on sites where the B layer is at least deeper than 25 cm.

Brakee Pine Ridge (Profile VII - IX).--Judging from the size and vigor of trees growing in this formation one can conclude that soil conditions are much better than in the Savanna Pine Ridge. The surface soil is not as acid as in the Savanna Pine Ridge, presumably because of the character of the humus. Movement of Fe is therefore limited but that of Si is increased. The humus has mull-like characteristics with

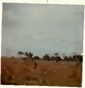


Figure 5.--Scattered *P. caribaea* trees on a low productivity site of the Savanna Pine Ridge (soil Profile 1)

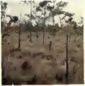


Figure 6.--*P. caribaea* stand on medium productivity site of the Savanna Pine Ridge (soil Profile II).

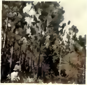


Figure 7.--*P. caribaea* stand on high productivity site of the Savanna Pine Ridge (soil Profile III).

a [illegible] of base saturation. Both the A and B horizons are high in sand and the massive clay is located at depths below 80 cm.

The granitic parent material probably contains nutritive minerals and thus affects the soil in two ways, the quartz contributing to the coarse texture and the minerals resulting in a relative fertile soil. A good structure and consistence is maintained to a greater depth than in most soils of the area. Consequently, aeration and root penetration go much deeper than in the pine savannah. Trees have more nutrients at their disposal and are capable of supplying the surface soil with a heterogeneous layer of litter. Mottling was almost absent, which indicated good drainage. Red color dominated in this soil, indicating intense oxidation of Fe.

On the good sites, trees attain 15 m height and 27 cm DBH in 15 years, while on low quality sites they attain 15 m in 25 years with a DBH of 26 cm (Table 18). The latter is found on sites with a flat topography. Drainage is poorer and the massive layer is found at a lower depth (50 - 60 cm).

Melinda Coastal Pine Ridge (Profile IX - XII).--Trees in this formation give a general appearance of better growth and vigor than those in Savanna Pine Ridge. As the climate (rainfall and temperature) in the two areas do not differ greatly, differences in tree growth must be due largely to soil features. A study of morphological characteristics suggested that differences in parent material and soil texture are the principal causes for the varieties in growth.

The Savanna Pine Ridge soils are derived from old alluvia transported from the north and in turn were composed mainly of the finest fractions of river alluvial materials originating from the Maya Mountains

The weathering products are, therefore, primarily clays. The soils of the Melinda Coastal Pine Ridge are underlain by river alluvia and colluvia deposited by rivers and creeks coming from the eastern fringe of the Maya Mountains. The parent rocks are acidic igneous, such as granites, slates and schists, that give off sandy materials on weathering.

The A_1 horizon is dark, because of the humus, mostly raw humus, and is probably responsible for mobilization of the Fe. The A_2 and B_1, eluviated horizons, are mostly light colored with a yellowish shade and mottling, which suggests that drainage is not ideal and has caused some Fe reduction. The internal drainage on sites with sloping and normal relief is not impeded. Because the texture is sandy from top to bottom, water and air move much easier than in the Savanna Pine Ridge. The limiting factor for growth is the external drainage particular to sites with flat relief. Movement of soil separates from the surface soil downward results in clogging of pores and formation of massive layers in the subsoil. On the good sites these layers are deeper than 60 cm and trees attain a height of 13 m and a DBH of 17 cm. On the low productivity sites, the maximum height of trees was 5 m with a DBH of 11 cm (Table 18). These sites were associated with a concave topography and, consequently, a high water table.

Mountain Pine Ridge (Profile XIII).--The structure and consistence of soils from this area, particularly from hilltops, are poor. Pines under similar circumstances on the lowland would show a poor growth. Apparently soil structure and consistence do not greatly influence growth of pines in the Mountain Pine Ridge. On the other hand, one might ascribe the good tree growth of the area to higher elevation and correspondently cooler temperatures. However, this reasoning is a little hard to accept because pine growth is also good in the [illegible] Pine Ridge with a tropical lowland climate.

It is possible that the presence of gravel and pebbles in the soil profile are beneficial to the growth of pines in the Mountain Pine Ridge (Figure 8). Soil physical conditions are probably better for tree growth than might be concluded from a mechanical analysis in the laboratory, as pebbles and gravel are largely ignored in this determination of texture. Pebbles and gravel may actually contribute to good aeration and moisture conditions. On the sampled site, which is admittedly not one of the best of the region, trees attained a height of 15 m and a DBH of 30 cm (Table 18). This was much greater than trees in the Savanna Pine Ridge, despite the calculated clay content of 35-40% in the topsoil of the former. Lower values for clay content would result if pebbles and gravels were included in the analyses.

The variation in growth between the different sites within the Mountain Pine Ridge is probably related to slope. Sites with an excessive relief show a rapid to very rapid run off and more erosion than areas with less slope. Pines appear to grow better in the valleys, foothills, river banks and level lands (Figure 8).

Northern Pine Ridge (Profile XIV).--Soil fertility in the Northern Pine Ridge is likely to be higher than in the other pine lands. This conclusion is based on the fact that sections of the Northern Pine Ridge are used for shifting cultivation, a practice usually confined to the better soils. The number of natural plant species growing within the plant community is higher than in other pine localities. Calciphilic species grow here together with pine, which indicates that Ca and consequently pH and CEC are somewhat higher than in soils under the other

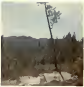


Figure 8.--General view of the Mountain Pine Ridge.

pine ridges. Because of these properties and low annual rainfall, loss of nutrients by leaching is reduced. The occurrence of several species belonging to the legume family, not found in the other formations, was striking. It is to be expected that soil N status was improved by these Leguminosae.

The growth of young pine in this area is fast. Trees made particularly good height growth on the recently burned milpas. Unfortunately no measurements were made of trees in the old milpas. Pines would be eliminated from this zone, because of human actions and heavy competition from associated species, if they were not somewhat fire tolerant and fast growing (Fig. 9).

This pine ridge has an extremely flat topography and it appeared that internal drainage is somewhat impeded, but it affects growth of pines not as much as in the Savanna Pine Ridge because of the drier climate. Above the 18° N latitude, pines do not grow naturally, because the climate becomes too arid for this species.

Soil chemical factors

Soil reaction (pH).--The pH of the surface soil was generally low in all areas, but variation between different physiognomies were noted. The Mountain Pine Ridge, Savanna Pine Ridge, and Melinda Coastal Pine Ridge had the lowest pH values of all surface soils, with averages of 4.50, 4.79, and 4.63, respectively. The soil pH in the Broken Pine Ridge was intermediate (pH 5.14) and that of the Northern Pine Ridge was the highest (pH 5.94) of all soils tested. The soil reaction of the whole profile ranged from strongly acid to very strongly acid. These low pH values were most likely the result of climate and the soil forming materials. An intense leaching of bases takes place in areas with a humid climate, such as British Honduras, whereupon the exchange

Figure 8.--A group of *P. caribaea* trees in the Northern Pine Ridge.

sites on the soil colloid become largely occupied by H^+ and Al^{3+}. The pine ridge soils in the lowlands are weathering products of erosion materials transported from the Maya Mountains, which are built primarily of acidic igneous and metamorphic rocks (Luckhoff 1964). The difference between pH H_2O and pH KCl was slight, which was an indication that exchangeable H was low, most of the exchange sites were probably occupied by Fe or Al.

Variations in pH among the different pine ridges are apparently related to variations in composition of the vegetative cover or climate. In the Broken Pine Ridge where pines grow together with hardwoods, soil pH tended to be higher than in plant formations where pines are associated with a grassy vegetation. The dry climate and the underlying calcareous sediments are probably responsible for the relatively high pH in the Northern Pine Ridge.

In many profiles, particularly soils under pure pine stands, the pH of the uppermost horizon is lower than that of the underlying layers. This is probably the effect of organic acids resulting from the decomposition of needles. In the Broken Pine Ridge and Northern Pine Ridge where the litter is less acid than in pure pine stands, soil pH tended to decline with depth.

The good growth of pines in many sections of the Broken Pine Ridge is apparently an indirect affect of pH, since increased availability of P and the bases is associated with the higher pH.

The effect of soil acidity on growth of *P. caribaea* appears to be reciprocal. As a result of the low pH, pines dominate the site, but conversely, high acidity and poor conditions of the pine ridge soils in British Honduras were to a great extent by-products of the growth of generation after generation of *P. caribaea*, which were permanently sustained in pure stands by forces of nature and man. Charter (1940) predicted that in the long run soils of the pine ridge would become unsuitable for pines. Lamb (1966) also suspected that pine ridge soils were deteriorating in some sections. He based this conclusion on his observation of the acid clay deposits of the coastal plains in that country where *P. caribaea* will not grow successfully, even after drainage and fertilization.

No conclusion can be drawn from this data with regard to an optimum pH within a particular physiognomic unit. Differences in pH are relatively small and often erratic among the sites. The collected data suggest that a pH range from about 4.0 to 6.3 should be ideal for the growth of *P. caribaea*.

Organic matter.--It seems that, as in temperate zones the organic matter developed under pure pine stands resembles mor-type humus material while that under the mixed community of the Broken Pine Ridge resembles the mull-type. Mor humus is typically acid and does not stimulate growth of pines, while mull humus mineralizes faster, has a higher base saturation (Halsi 1964), and consequently beneficial to pine growth as demonstrated on the Broken Pine Ridge.

The high organic matter content of the Savanna Pine Ridge soils is probably due to the fact that the soil is wet for extended periods, whereby decomposition and mineralization is slowed down. The cool temperature of the Mountain Pine Ridge may be influential in lowering the rate of decomposition of organic matter.

It appears that soils of high producing sites of the Savanna Pine Ridge have a higher organic matter content than sites of low producativity which is probably the effect of a greater production of litter on the relatively better soil (Table 19). The low producing sites are also more open, a condition that speeds up decomposition of organic matter.

The differences of organic matter content among the various sites within the Melinda Coastal Pine Ridge and Broken Pine Ridge are very slight. Organic matter in all profiles decreases with depth, the change is often very abrupt (Table 19).

Nitrogen and C/N ratio.--The total N content of pine ridge soils appears favorable for tree growth (Table 19). Contents of surface layers of these tropical soils are not lower than minimum soil fertility standards for Coniferous plantations set by Wilde (1958) for Wisconsin--the only comparative standards available.

Nitrogen in the A_1 horizon is always higher than in layers underneath and there is a positive relationship between organic matter and N content. The N content in the surface soil of the Savanna Pine Ridge was fairly high, with 0.104% on the average, while in the Broken Pine Ridge it averaged only 0.079%. Blue-green algae often cover soil surface in the Savanna Pine Ridge, particularly on the wettest sites. These algae may be capable of non-symbiotic N fixation. A soil moisture content which only fluctuates within narrow ranges, in combination with a high soil Na content, provide optimum conditions for these algae. Algae were also observed by Helbig (1959) on soils of the wet pine savannas "suampos" in Mosquitia, Honduras.

Yet the high N content in savanna soils is not reflected in good growth of pine. The Broken Pine Ridge, which has a lower content of soil N than the savanna, supports a more vigorous growth of trees. It is likely that the greater part of N in savanna soils is organic N,

TABLE 18

CHEMICAL ANALYSES OF SOILS SUPPORTING STANDS OF *P. caribaea* VAR. *hondurensis* IN BRITISH HONDURAS

Profile no.	Horizon	Depth	pH		Organic matter	C	N	C/N	Total P	Extractable nutrients[1]								CEC
			H_2O	KCl						P	K	Ca	Mg	Na	Fe	Al	Mn	
		cm			--------	%	--------	ratio	----------	----------	----------	----------	ppm	----------	----------	----------	----------	meq/100 g
						Savanne Pine Ridge												
I	A_1	0-15	6.08	4.31	1.78	1.02	0.08	13.25	58	2	22	45	25	40	73	155	0.30	4.22
	A_2	15-23	4.83	4.31	0.63	0.36	0.04	10.00		1	21	45	25	120	2	105	0.20	1.24
	B_{1t}	23+	4.69	4.15	1.01	0.12	0.04	27.27		1	31	45	87	125	2	166	0.40	0.21
II	A_1	0-10	4.67	3.89	1.81	1.05	0.07	14.98	58	3	24	65	30	115	34	85	0.60	3.42
	A_2	10-18	5.20	4.59	0.99	0.58	0.02	13.32		2	8	85	25	105	8	95	0.40	0.88
	B_1	18-32	5.10	4.56	0.64	0.37	0.02	21.71		1	28	80	38	105	4	95	0.40	1.31
	B_{21}	32-45	5.26	4.65	0.57	0.33	0.02	14.00		1	26	45	50	115	2	90	0.40	1.99
	B_{22}	45+	5.45	5.00	-	-	0.01	-		1	32	25	25	80	2	85	0.40	2.20
III	A_1	0-8	4.56	4.20	6.20	3.60	0.28	12.62	82	4	27	85	45	115	66	950	1.20	12.60
	B_{11}	8-18	4.61	4.22	2.17	1.25	0.07	18.02		2	37	10	45	300	35	645	0.60	6.45
	B_{12}	18-25	4.48	4.11	0.76	0.44	0.06	7.32		1	27	10	20	110	16	830	0.60	5.81
	B_{21}	25-45	4.55	4.21	1.06	0.63	0.06	10.06		1	44	10	35	130	7	225	0.50	3.39
	B_{22}	45-55	4.78	4.38	0.95	0.56	0.06	9.08		1	60	10	40	130	5	165	0.30	6.15
	B_{3t}	55-78	4.84	4.28	0.45	0.26	0.04	6.29		0	37	10	60	125	2	235	0.20	6.14

TABLE 13--Continued

Profile no.	Hori-zon	Depth	pH H_2O	pH KCl	Organic matter	C	N	C/N	Total P	Extractable nutrients[1] P	K	Ca	Mg	Na	Fe	Al	Mn	CEC
		cm			--------	%	--------	ratio	----------	----------	----------	----------	ppm	----------	----------	----------	----------	meq/ 100 g
								Savonna Pine Ridge (Continued)										
IV	A_1	0-8	4.58	4.26	4.18	2.43	0.21	11.74	64	3	37	5	25	120	22	520	0.50	6.53
	A_2	8-18	4.63	4.33	1.74	1.01	0.09	11.21		1	31	5	45	115	11	420	0.60	3.50
	A_{22}	18-23	4.60	4.29	0.61	0.53	0.04	12.52		1	38	20	25	115	5	150	0.50	1.54
	B_{21t}	23-40	4.66	4.18	0.68	0.67	0.07	6.44		0	35	10	52	130	6	170	0.40	4.42
	B_{22t}	40-60	4.71	4.19	0.56	0.34	0.03	11.66		-	45	35	75	192	2	165	0.50	5.35
	B_{3t}	60-82	4.53	4.10	0.43	0.25	0.03	6.31		-	34	10	32	135	6	195	0.40	6.06
V	A_1	0-8	4.51	4.13	5.60	3.42	0.24	14.48	47	2	44	10	32	135	27	416	1.10	10.31
	A_{21}	8-15	4.64	4.30	1.83	1.06	0.08	12.57		1	27	10	15	100	16	320	0.60	3.85
	A_{22}	15-30	4.60	4.30	0.61	0.34	0.02	14.73		1	22	10	15	100	5	140	0.30	2.24
	B_{1t}	30-45	4.81	4.32	0.84	0.46	0.04	12.30		0	34	15	37	110	3	160	0.60	4.60
	B_{2t}	45-65	5.00	4.50	0.53	0.31	0.03	10.28		-	-	60	165	130	2	135	0.40	6.07
	B_{3t}	65-90	5.14	4.60	0.43	0.25	0.02	10.04		-	20	160	185	125	1	125	0.40	5.31
VI	A_1	0-10	4.57	4.21	1.50	0.87	0.05	16.83	27	4	20	36	18	86	16	115	0.50	8.38
	A_2	10-25	5.17	4.60	0.72	0.42	0.02	12.28		2	14	76	15	86	8	140	0.50	1.86
	B_{1g}	25-43	4.50	4.20	0.61	0.65	0.02	15.80		1	22	46	15	115	7	165	0.40	2.39
	B_{2g}	43-60	4.83	4.36	0.51	0.36	0.02	18.83		1	42	55	36	140	4	130	0.40	2.43

TABLE 18--Continued

Profile no.	Horizon	Depth	pH H$_2$O	pH KCl	Organic matter	C	N	C/N	Total P	Extractable nutrients[1] P	K	Ca	Mg	Na	Fe	Al	Mn	CEC
		cm			-------	% -------		ratio	----------------			ppm			----------------			meq/ 100 g
								Broken Pine Ridge										
VII	A_1	0-18	5.17	4.55	2.78	1.61	0.12	12.36	118	3	44	110	40	135	12	225	32.40	4.85
	A_2	18-23	5.10	4.50	1.77	1.03	0.08	13.86		3	32	50	20	105	17	255	53.00	3.54
	B_1	23-40	4.85	4.21	0.46	0.37	0.04	6.30		1	27	85	20	105	15	135	32.00	2.48
	B_{2t}	40-65	4.55	4.05	0.33	0.18	0.02	10.21		-	40	160	75	125	3	110	41.50	8.31
	B_{3t}	65-100	4.45	4.01	0.25	0.15	0.00	23.17		1	52	100	160	135	2	115	8.40	5.58
VIII	A_1	0-15	5.20	4.23	2.30	1.33	0.10	13.38	67	6	40	210	40	140	8	105	6.50	5.19
	A_2	15-30	5.55	4.60	1.46	0.85	0.04	19.23		4	40	150	35	175	8	110	1.40	2.00
	B_1	30-55	5.88	4.81	0.68	0.38	0.01	33.31		2	31	105	33	140	3	105	0.80	1.30
	B_{21}	55-80	5.85	4.72	0.26	0.15	0.00	62.51		2	50	170	33	140	2	80	0.80	0.80
	B_{22}	80-124	5.07	4.80	0.25	0.14	0.00	38.51		0	38	175	33	185	4	80	0.20	1.30
	B_3	124+	5.00	4.30	0.17	0.10	0.01	18.84		0	37	85	33	180	2	85	0.80	1.77
IX	A_1	0-13	4.70	4.00	2.44	1.42	0.10	14.75	58	4	88	125	60	180	7	100	2.40	4.80
	A_2	13-30	5.14	4.48	0.93	0.57	0.03	18.82		4	52	138	35	165	6	85	0.80	3.77
	B_1	30-52	5.43	4.65	0.03	0.06	0.02	3.21		1	63	180	35	140	11	85	0.40	1.53
	B_{21t}	52-67	5.00	4.30	0.21	0.12	0.02	4.34		1	33	100	38	125	6	85	0.40	1.18
	B_{22t}	67-83	4.73	4.12	0.53	0.30	0.02	12.65		0	40	100	63	140	8	138	0.80	1.53

TABLE 19--Continued

Profile no	Horizon	Depth	pH H$_2$O	pH KCl	Organic matter	C	N	C/N	Total P	Extractable nutrients[1] P	K	Ca	Mg	Na	Fe	Al	Mn	CEC
		cm			-------- %		--------	ratio	-------------	-------------	-------------	ppm	-------------	-------------	-------------	-------------	-------------	meq/100 g
								Melinda Coastal Pine Ridge										
X	A_1	0-13	4.51	4.13	2.58	1.50	0.08	25.78	76	3	33	65	35	125	12	180	0.70	3.42
	A_{21}	13-20	4.55	4.30	1.55	0.49	0.03	16.88		2	58	78	30	140	8	105	0.30	1.42
	A_{22}	20-45	4.80	4.30	0.18	0.09	0.03	3.66		2	27	130	30	115	4	85	0.40	0.62
	B_{1t}	45-78	4.81	4.32	0.53	0.31	0.02	18.76		1	81	135	45	180	2	70	0.40	1.00
	B_{2t}	78-80	5.00	4.50	0.21	0.12	0.01	18.60		1	33	125	40	130	2	70	0.40	1.24
XI	A_{11}	0-5	4.60	3.80	2.33	1.35	0.06	22.87	71	4	35	185	48	115	8	78	0.90	4.56
	A_{12}	5-13	5.08	4.40	1.11	0.64	0.04	17.88		2	43	85	40	115	20	180	0.80	2.12
	A_2	13-25	5.21	4.50	1.06	0.62	0.05	13.54		2	32	85	33	115	11	215	0.50	1.69
	B_1	25-55	5.21	5.71	0.13	0.08	0.01	8.88		1	30	130	33	110	2	65	0.30	1.30
	B_2	55-72	5.00	5.25	0.17	0.10	0.01	8.73		1	23	140	30	95	2	65	0.50	1.52
XII	A_1	0-15	4.80	4.25	2.31	1.34	0.06	21.44	58	3	38	68	38	105	5	120	0.60	3.07
	A_2	15-30	5.30	4.10	0.10	0.05	0.02	32.00		1	37	155	186	120	3	75	0.40	1.83
	B_1	30+	5.30	5.65	0.27	0.18	0.02	10.13		2	130	125	78	175	29	235	1.10	0.41
								Mountain Pine Ridge										
XIII	A_2	0-8	4.37	3.30	2.89	1.67	0.08	20.28	37	2	58	255	40	230	5	75	0.50	5.84
	B_{1t}	8-23	4.52	4.00	1.16	0.69	0.04	18.80		0	110	55	135	140	8	160	0.80	3.94
	B_{2t}	23-47	4.60	4.00	0.41	0.24	0.02	15.18		–	124	45	180	180	2	125	0.40	3.18
	B_{3t}	47-82	4.72	4.04	0.27	0.15	0.01	21.55		–	130	65	180	160	2	115	0.40	4.19
	C	82+	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–

TABLE 12--Continued

Profile no.	Horizon	Depth	pH		Organic matter	C	N	C/N	Total P	Extractable nutrients[1]								CEC
			H_2O	KCl						P	K	Ca	Mg	Na	Fe	Al	Mn	
		cm			-------- % --------			ratio	------------------				ppm	------------------				meq/ 100 g
							Northern Pine Ridge											
XIV	A_1	0-13	5.58	4.60	2.60	1.51	0.04	41.88	69	4	96	260	170	115	3	70	3.70	4.13
	A_2	13-23	6.30	5.70	0.31	0.16	0.01	14.32		3	67	175	110	88	4	60	0.40	6.02
	B_{1t}	23-30	4.83	4.01	0.69	0.40	0.03	15.22		1	110	385	400	135	14	155	0.40	22.41
	B_{2t}	30+	4.45	3.60	0.63	0.36	0.03	10.81		-	136	760	400	185	5	265	0.40	10.66

[1] $\underline{N}$ NH_4OAc, buffered at pH 4.8.

which is not available for plant growth. Under the prevalent conditions such as low pH and waterlogging, mineralization of organic matter is probably slow.

Table 18 shows that within the Savanna Pine Ridge and Broken Pine Ridge, soils of high producing sites contained more N than low ones, while in the Melinda Coastal Pine Ridge a total N - growth relationship was not apparent.

C/N ratios calculated for surface soils in the Savanna Pine Ridge were all below 15, which might be attributable to the N contribution of blue-green algae. Soils of the Broken Pine Ridge, supporting higher producing stands, had C/N ratios of about the same range, but in contrast to the savanna soils, they are here probably the result of a reasonably good mineralization of N from the soil organic matter.

The C/N ratios of surface soils in the Melinda Coastal Pine Ridge, Mountain Pine Ridge and Northern Pine Ridge are all higher than the critical level of 15 as proposed by Broadbent (1957), which is an indication of a low rate of mineralization of organic matter. In addition N in pine ridge soils might be lost by leaching as a consequence of sandy surface horizons, by denitrification particularly in waterlogged sites and by fires, processes affecting C/N ratios.

Total and extractable P.--Analysis of surface soils for total P gave values ranging from 47 to 64 ppm in the Savanna Pine Ridge, 55 to 118 ppm in the Broken Pine Ridge, 59 to 79 ppm in the Melinda Coastal Pine Ridge, 37 ppm in the Mountain Pine Ridge, and 68 ppm in the Northern Pine Ridge (Table 19). More than half of the sampled sites had values lower than the critical level (70 ppm P) for slash pine proposed by Baur (1959) in Australia (cited by Pritchett and Llewellyn

1966). Only three sites had a total P content higher than this limit (VII, X and XI), they show excellent growth. These low figures might be expected because the soils of British Honduras, particularly the soils under pines, are weathering products of igneous, metamorphic and sedimentary rocks that are poor in phosphates (Romney 1959). Apatite, the mineral source of most soil P, is not listed by Krueger (1963) as one of the minerals found in river sediments in British Honduras. Because of the absence of a mineral source it would be logical to assume, that the greater part of soil P was derived from readily mineralizable organic materials.

Soil P extracted with NH_4OAc (pH 4.8) did not exceed 5 ppm in any of the profiles (Table 19). As a consequence, these soils are classified as 'deficient in phosphates' (McGeorge 1939). Hardy _et al._ (1935) extracted P from samples of four profiles in the Melinda Coastal Pine Ridge and of one in the Northern Pine Ridge with 0.01% H_2SO_4 (Truog solution) and found them to contain about the same amount of P as reported herein. Romney (1961) found Puletan loamy sand, a common soil type supporting pines to contain between 3 and 4 ppm extractable P.

In all profiles the amount of extractable P decreased with depth, indicating that most of the soil P is involved in the vegetation cycle.

Of all the soils analyzed, soils of the Broken Pine Ridge had on the average the largest amounts of total and available P (Profile VIII and IX). These soils are also deeper than the others, thus permitting roots to withdraw nutrients from a greater depth, enriching the upper soil layers with litter fall. Pines grow together with hardwoods in this area producing a mixed type of litter that supports a heterogeneous soil fauna population. Decomposition of litter and mineralization and cycling of P presumably were [illegible] completely under these conditions.

On all sites the growth of pines was apparently related to the amount of total and extractable P.

Extractable K.--This study reveals that an apparent inverse relationship exists between annual rainfall and amount of extractable K. Table 18 shows that Savanna Pine Ridge with the highest mean annual rainfall contains the lowest amounts of extractable K (37 ppm), while the pine forest soils in the semi-arid sections of British Honduras were highest in extractable K (Mountain Pine Ridge contained 62 ppm and Northern Pine Ridge contained 53 ppm). Areas with intermediate rainfall were also intermediate in the amounts of soil extractable K (Melinda Coastal Pine Ridge soils contained 45 ppm and Broken Pine Ridge soil averaged 46 ppm). The K content of these soils run from low to medium high (Hardy et al. 1936).

The deeper horizons were often higher in extractable K than surface soils. In the Savanna Pine Ridge, large amounts of K were immobilized in the vegetation and frequent fires that swept over the area were helpful in replenishing the soils with this essential element. The K status of soils of the remaining pine area in British Honduras is apparently not critical. K bearing minerals such as feldspars, muscovite, biotite and glaucophan are probably the sources of soil K. Krueger (1963) showed the presence of these minerals in clay samples taken from rivers in British Honduras.

No data are available about the K requirement of P. caribaea. The minimum fertility standard set by Wilde (1960) assigned for Jack pine (P. banksiana) was around 60 kg K per ha in the upper 15 cm layer.

All sites except those in the Savanna Pine Ridge, more or less meet this requirement (Table 30).

Data in Table 19 suggest a positive relationship between soil extractable K and tree growth.

Extractable Ca --Extractable Ca in the pine ridge soils varied considerably with location (Table 19). The Savanna Pine Ridge had the lowest content, with values between 5 and 65 ppm in the surface soil. The Melinda Coastal Pine Ridge had an average of 105 ppm and the Broken Pine Ridge as much as 140 ppm extractable Ca. The Mountain Pine Ridge, despite its origin from underlying acidic rocks, had an average of 154 ppm. As expected, the Northern Pine Ridge soils with 265 ppm contained the highest Ca values of all soils. It is interesting that in Profile XIV the Ca content in the B_2 horizon is 740 ppm while that of the B_1 is 285 ppm. This finding supports Charter's contention (1940) that these soils are enriched by Ca-charged groundwater from the underlying calcareous sediment. Data in Table 19 also suggest a relationship between rainfall and distribution of Ca in the soil. However, no relationship could be found between extractable Ca and growth rate of pines within a particular pine ridge.

There are no standards by which to judge whether the Ca status of British Honduras soils is satisfactory for pine growth. Very little research has been conducted on Ca in soils of the tropics. Transfer of temperate zone experiences with this nutrient should be done with caution. For example, lime, in combination with high moisture and temperature, encourages microbial activity leading to accelerated decomposition and mineralization of organic matter. Not all tropical acid soils respond to applications of limestone. Nonetheless, by most any standard the majority of the pine ridge soils can be qualified as extremely low in Ca, and the fact that trees survive in such environment is proof of their low requirement for Ca.

Extractable Mg.--Results of extractions of soils with NH_4 OAc buffered at pH 4.8 show that all profiles, except those from Mountain Pine Ridge and Northern Pine Ridge, have less than 60 ppm Mg in the surface soil, thus falling in the extremely low class (Schroo 1963).

Hardy et al. (1936) analyzed for Mg in some British Honduras soils and their parent rocks. He found that soils derived from granites are richer in Mg than soils derived from sandy or slaty schists. This probably explains the relatively high Mg content of subsoil in the Mountain Pine Ridge. Limestone underlying the soils is probably the Mg source in the Northern Pine Ridge.

There are indications that rate of growth of pines is related with the amount of extractable Mg in the surface soil (Table 18). There was no unanimity among research workers with regard to the critical limits of available Mg in soils for plant growth.

Kraus (1964) set the lower limit at only 10 ppm. Investigations of Goor (1965) provide a better guideline. After a study of 5-year-old P. elliottii in Brazil he came to the conclusion that optimum growth for that species was attained if exchangeable Ca plus Mg totaled 1.0 meq/100 g soil (approximately 10 mg Ca + 6 mg Mg/100 g). Conditions for optimum growth in relation to Mg supply are thus present in the pine ridge soils in British Honduras.

Extractable Na.--Extractable Na in surface soils of the British Honduras pine ridge ranged from 40 ppm to 230 ppm, with the following averages.

a) Savanna Pine Ridge soils	123 ppm
b) Melinda Coastal Pine Ridge soils	148 ppm
c) Broken Pine Ridge soils	148 ppm
d) Mountain Pine Ridge soils	185 ppm
e) Northern Pine Ridge soils	105 ppm

The source of Na in the British Honduras soils is most likely the minerals of the parent rocks, such as feldspars. Salt may have intruded in the lowland pine savannas during hurricanes, but Na is loosely held on the exchange complex and is easily replaced by other cations. Perhaps it is for these reasons that residual soils of the Mountain Pine Ridge and the Broken Pine Ridge are higher in Na than the alluvial soils that are closer to the sea.

The pine savannas in south British Honduras are of recent origin. They were probably covered by swamp and marsh vegetation, saturated with sea water, and gradually filled by marine alluvia. They probably originated in much the same fashion as the coastal plains in Guyana (Gesser 1961) and Cameroon (Brzesowsky 1962).

Sodium is not considered essential for most plants, therefore a lower critical limit has not been set for plant growth. It may have an indirect beneficial effect to the growth of P. caribaea by substituting for a part of the requirement for K, when this latter element is deficient (Hewitt 1963). Chemical analysis revealed that large quantities of Na are accumulated in the needles of P. caribaea (Table 20). Sodium possibly helps reduce soil acidity so that the environment is maintained suitable for pine growth despite the high Al and Fe content. Sodium apparently encourages development of blue-green algae which contribute N to the soil.

TABLE 20

ANALYSIS OF *P. caribaea* NEEDLES TAKEN FROM TREES IN THE VICINITY OF SOIL PROFILE PITS

Profile no.	N %	P %	N:P ratio	K %	Na %
		Savanna Pine Ridge			
I	0.63	0.04	25.44	0.36	0.25
II	1.22	0.05	25.63	0.62	0.16
III	1.28	0.04	29.56	0.81	0.37
IV	1.18	0.04	23.27	0.43	0.16
V	1.13	0.04	29.45	0.32	0.29
VI	0.62	0.03	30.97	0.52	0.20
		Broken Pine Ridge			
VII	1.26	0.05	25.41	0.55	0.24
VIII	1.61	0.05	28.70	0.34	0.15
IX	1.32	0.04	30.24	0.42	0.22
		Melinda Coastal Pine Ridge			
X	1.02	0.04	25.61	0.33	0.16
XI	1.16	0.05	25.04	0.36	0.25
XII	1.12	0.04	26.02	0.43	0.24
		Mountain Pine Ridge			
XIII	0.97	0.04	29.69	0.32	0.17
		Northern Pine Ridge			
XIV	1.08	0.04	27.23	0.36	0.16

Soil Na may also exert important undesirable effects on plant growth through adverse modification on soil structure. There is adequate evidence to support the assumption that high Na contents of the pine ridge are mainly responsible for the impermeability and waterlogging conditions of pine savannas. The disastrous consequences of Na on soil dispersion, bulk density, and hydraulic conductivity is more serious in acid than in alkaline soil (Martin et al 1964). In most profiles extractable Na increases with depth as does soil compactness.

These adverse effects are magnified on sites where the sandy surface layer is thin, where the land is flat, and where the rainfall is abundant. These conditions all exist in the Savanna Pine Ridge, affecting soil physical properties and indirectly growth of pines.

Extractable Fe.--The results of the NH_4OAc (pH 4.8) extractable Fe are presented in Table 19. The data indicate that the surface horizons in all profiles have the highest extractable Fe content. This is apparently the result of Fe returned to the surface through the vegetation cycle. Extractable Fe in the subsoil probably results from reduction of ferric into more soluble ferrous compounds by acidic extracts of litter which moves with percolating water.

Although Fe is the third most abundant element in soils and it fulfills a very important role in plant nutrition and metabolism, analyses of available or exchangeable Fe are very seldom part of soil surveys. It is not easy to find data on soil Fe for comparative purposes.

It appeared that frequently waterlogged profiles, as those in the Savanna Pine Ridge and Profile XII in the Melinda Coastal Pine Ridge were higher in extractable Fe in the surface soils than profiles with good drainage. Reduced conditions apparently make Fe better soluble, as hypothesized by Harter and McLean (1965). Under prolonged waterlogging conditions the solubility of Fe might become so high as to be toxic for plant growth, particularly in acid soils.

The data in Table 19 gave indication that variation in growth of *P. caribaea* among the various pine ridges are negatively related to the amount of extractable Fe in the surface soil, however no such relationship was found among sites within a particular pine ridge.

The surface horizons of all profiles in the Savanna Pine Ridge and Profile XII of the Melinda Coastal Pine Ridge have from 19 to 73 ppm extractable Fe, while those in all other profiles have much less (Table 19).

Extractable Mn.--The amount of extractable Mn in the pine ridge soils in British Honduras are presented in Table 19. It shows that all soils under *P. caribaea* except in the Broken Pine Ridge and Northern Pine Ridge were extremely low in extractable Mn in the surface soil. The majority of the soils had less than 1 ppm. The Broken Pine Ridge was best provided with extractable Mn, but it is still below the average for agricultural soils in the surrounding areas which was determined by Hardy *et al.* (1935) to be 1,000 ppm.

The main soil factors that determine Mn availability are soils pH and oxidation-reduction conditions. Soil pH values around 6-6.5 appear to be critical in this respect, lower values favoring reduction, higher values oxidation (Bould 1963). Several factors probably contribute to reduced conditions in pine ridge soils, such as high rainfall, organic acids released by decomposing needles, and poor drainage resulting from a flat topography or soil impermeability. Reduction of Mn^{3+} to Mn^{2+} makes it more soluble and mobile, permitting percolating water to remove Mn from root zone.

Variation in extractable Mn was noted between horizons within profiles. The extractable Mn in the pine ridge soils decreases with depth and apparently was related to organic matter content, which indicates that Mn participates in the vegetation cycle. Data in Table 19 also suggests that variation in amount of extractable Mn among profiles within pine ridge is influenced by drainage conditions.

The variation in extractable Mn among the pine ridges is probably related to nature of litter produced by the vegetation. Litter from pure pine vegetation has lower extractable Mn than mixed litter such as found in the Broken Pine Ridge and Northern Pine Ridge. A positive relationship exists between growth of pines and variation of Mn content within as well as among pine ridges.

Extractable Al.--The results of analysis of samples show that pine ridge soils of British Honduras have an extremely high Al content. One would suspect this from the occurrence in the field of plants adapted to very acid soil conditions as the Euterpe (Ahmad 1960) and Al accumulating plants such as Miconia (Romney 1959). Furthermore differential thermal analysis of the colloidal fraction showed large amounts of gibbsite and amorphous clays, which under these climatic conditions are normally composed of Al compounds.

The high Al content is in great part responsible for the high acidity of these soils.

Tisdale and Nelson (1967) explained the role of Al in soil acidification. They assumed that H^+ and Al^{3+} were in continuous equilibrium in acid soils. For example, an addition of H^+ to the soil solution results in an equivalent new supply of Al^{3+}, which comes from the crystal lattice of clay minerals. This demolition of clay crystals results in their transformation into amorphous colloids, which are commonly grouped as "allophane". Needle litter decomposition provides the H^+ for breakdown of clay and dissolving of Fe and Al in soils supporting pine vegetation. In this way, sesquioxides move downward with percolating water into the ground water. However, it is apparent that Al tends to accumulate in one of the subsoil horizons of the pine ridge soils due to inhibition of percolation by compacted soil layers.

The low values for extractable P in soils under *P. caribaea* are no doubt, partially due to P fixation by Al. The effect of soil Al in the savanna area is demonstrated by the poor growth and stand of the pine vegetation.

Adsorbed Al^{3+} was also probably responsible for low CEC. It is held so tightly that the effective exchange capacity is strongly reduced (Martin *et al.* 1964).

Aluminum is not an essential nutrient and plants tolerate the presence of soluble Al within very narrow limits and at very low levels. Many tropical soils are inclined to become Al toxic. Al dominates and blocks the exchange complex after removal of bases by heavy leaching.

In a culture solution, 1 ppm of Al was considered excessive at pH 4.5 by Bould (1963). Legumes can tolerate only 1-2 ppm Al (McLeod and Jackson 1965) while rice can grow quite well with 4 ppm (Lockard and McWalter 1958). Aluminum level of 3-24 ppm in soils are reported to be toxic for tobacco (Eisenmenger 1930). From these reports one would conclude that the Al status of soils from the *P. caribaea* sites is excessively high and perhaps toxic for many crops.

An inspection of the analytical data suggests the existence of a positive relationship ($r = 0.75$) between amounts of organic matter and extractable Al in the surface soil. This relationship can be expressed by the following equation:

$$y = 0.031\,x - 0.1171$$

in which x = extractable Al and y = organic matter, both expressed in kg/m^2 in the top 30 cm layer (Table 30). One could conclude from this equation that an increase in soil organic matter causes an increase in the solubility of Al, resulting in high extractable Al until it reaches a certain limit when it affects growth of *P. caribaea*. In practice this condition could result from the accumulation of organic matter as a consequence of prolonged fire protection or a high stand density. *P. caribaea* as many other tree species has a pH preference within certain limits. A reduction of pH below that limit may check growth of pines.

Cation-exchange capacity (CEC).--The total cation-exchange capacities (CEC) of all horizons were very low in the soils. They ranged from 1 to 22 meq/100 g of soil.

The low CEC of British Honduras pine ridge soils are probably the result of the following factors:

1. The greater part of the clay fraction was made up of 1:1 clay minerals and allophanes.
2. Low soil pH.
3. High content of Al, which tends to form Al $(OH)_3$ and block exchange sites (Jenny 1961).
4. The presence of high amounts of exchangeable Al, which was so tightly held that it reduced effective CEC (Martin *et al.* 1964).

5. The sandy texture of the surface soil
6. Intense weathering

The CEC is highest in the top horizon, because this property is related to the organic matter produced by the processes cycling and decomposition. CEC decreases in the leached zone (A_2) due to low clay and organic matter content of this layer. It tends to increase again in the lower B horizons.

There are indications from data in Table 19, that variation in CEC of surface soils among profiles are related with amount of organic matter. The correlation coefficient expressing this relationship in the surface horizon is 0.73. Subsoil CEC is possibly related to the amount of clay. Sandy subsoils as in the Broken Pine Ridge and the Melinda Coastal Pine Ridge have lower CEC than the clayey subsoils of the Savanna, Mountain and Northern Pine Ridge.

Variations in growth of *P. caribaea* among and within the pine ridges are not reflected in CEC data presented in Table 19.

Needle analysis of *Pinus caribaea* from natural stands

Results of analysis of foliage from trees in the vicinity of the soil sample areas are given in Table 20. Analytical data of this type may be used to determine the adequacy of soil mineral supply and to diagnose mineral deficiencies (Kramer and Kozlowski 1960)

Tissue analysis, as a measure of soil fertility, has a number of limitations, such as micro-variation within site, species differences, and seasonal fluctuation in nutrient contents (Miller 1966, Melley and Shier 1965, Wells and Metz 1963, Metz *et al.* 1966, Pritchett 1968) They are nonetheless useful for comparisons with similar studies in other areas.

Nitrogen content of needles did not always reflect the total nitrogen in the soil. However, it was noted that the highest tissue N percentages were from trees on soils of the Broken Pine Ridge, which is considered to contain the best sites. A similar correlation was found by Rehfuess and Moll (1965) for spruce in Germany.

A N content of 1.40% or lower has been used as an indication that the soil was deficient in N (Heinsdorf 1965). Using this guide, one might conclude that only soils represented by Profile VIII had an adequate supply of N. However, the total N content of these soils was only 2,702 kg/ha in the upper 30 cm, as compared to 4,407 kg/ha for soils represented by Profile III (savanna) (Table 30). It was likely that N in the soil of the Broken Pine Ridge was more readily available than that of the savannas, because of the mixed nature of the organic matter and more favorable conditions for decomposition and mineralization.

Tissue P content of less than 0.058% was reported to be deficient for slash pine in Australia (Baur 1959, cited by Pritchett and Llewellyn 1966). Although the sampling techniques were not the same this value is considerably higher than the P content of P. caribaea needles included in this study and strengthens conclusion of P deficiency from the low P contents found by soil analysis. As consequence of the low P content, N:P ratios in these soils were found to range from 23 to about 31. The normal value set by Strebel (1960) for pines in Germany varies between 8 and 12.

The needle contents of K ranged between 0.32% and 0.62%. Needles from the Savanna Pine Ridge were highest in K. These relatively high values are indications of sufficient available K in these forest soils.

The deficiency limit set by Heinsdorf (1965) was 0.35% K for Scotch pine in Germany. He found that when leaves contained more than 0.35% K, trees will not respond to K fertilization.

The Na contents of needles were high, a reflection of the excessive Na found in the pine ridge soils. However, no relationship existed between Na content of needles and extractable soil Na of the site. Na is not considered essential for tree growth (Kramer and Kozlowski 1960) and little attention has been given so far to Na contents of various trees (Young *et al.* 1965).

Physical and mineralogical soil factors

Bulk density, particle density and total pore volume.--In this study no distinction was made between capillary (micro) and noncapillary (macro) pores, so that any conclusions drawn relative to these properties must be considered in context with texture. It appeared that the best sites had lower bulk densities than poor quality sites (Table 21). Critical bulk density values for root penetration of most plants are 1.75 g/cc for sand and 1.83 g/cc for clay (Wiersma 1959). For corn, this limit may be lower (Bertrand and Kohnke 1957), namely, 1.5/cc. It appeared that high bulk densities are also associated with high water tables (Profiles 1, II, and XII).

It was observed in almost all profiles that particle density of surface soil is somewhat lower than that of the subsoil. Soils with a particle density of 2.5 g/cc, or lower, have high organic matter content (Donahue 1965). Particle density is often employed in the identification of minerals, however it is of limited value for identification or classification of soils, because the particle density of most soils fall within a narrow range.

TABLE 21

PHYSICAL PROPERTIES AND MOISTURE RETENTION DATA OF SOILS SUPPORTING *P. caribaea* IN BRITISH HONDURAS

Horizon	Sample depth	Bulk density	Particle density	Total porosity	Moisture retained 1/3 bar	Moisture retained 15 bar	Available moisture storage capacity Horizon	Available moisture storage capacity Upper 60 cm
	cm	g/cc	g/cc	volume %	volume %	volume %	cm	cm
				Savanna Pine Ridge				
				Profile I: Puletan loamy sand				
A_1	0-15	1.52	2.55	34	6.59	2.46	4.13	1.00	
A_2	15-23	1.64	2.64	27	10.76	4.61	6.15	0.95	
B_1	23+	1.53	2.53	46	30.81	24.50	6.41	3.63	5.58
				Profile II: Puletan loamy sand				
A_1	0-10	1.54	2.64	42	5.33	2.69	2.64	0.60	
A_2	10-16	1.71	2.63	35	5.15	3.13	2.02	0.28	
B_{1t}	16-32	1.47	2.67	35	7.10	4.88	2.22	0.45	
B_{21t}	32-45	1.71	2.65	46	16.77	10.34	6.43	0.71	
B_{22}	45+	1.76	2.64	33	17.32	12.76	4.56	1.21	3.29
				Profile III: Puletan loam				
A_1	0-8	0.84	2.16	57	29.08	17.07	12.01	1.13	
B_{11}	8-16	1.24	2.50	50	20.39	14.57	5.82	0.56	
B_{12}	16-25	1.40	2.56	45	19.14	14.39	4.75	0.46	
B_{21}	25-45	1.41	2.59	46	25.13	15.27	9.86	1.65	
B_{22}	45-55	1.25	2.50	45	30.25	22.82	7.43	0.83	
B_{3t}	55-76	1.38	2.46	44	28.55	22.66	5.89	0.41	5.16

TABLE 21--Continued

Hori-zon	Sample depth cm	Bulk density	Particle density	Total porosity	Moisture retained 1/3 bar	Moisture retained 15 bar	Available moisture storage capacity Horizon	Available moisture storage capacity Upper 60 cm
		------ g/cc	------	----------	volume %	----------	----- cm	------
				Profile IV	Puletan loam			
A_1	0-8	1.14	2.55	55	18.48	12.44	7.05	0.64	
A_{21}	8-18	1.30	2.63	51	12.85	10.85	2.00	0.26	
A_{22}	18-23	1.47	2.48	41	11.20	9.56	1.64	0.12	
B_{21t}	23-40	1.33	2.63	49	22.74	18.77	3.97	0.67	
B_{22t}	40-60	1.37	2.56	47	28.81	24.56	4.25	1.16	2.85
B_{3t}	60-82	1.41	2.74	48	33.72	27.83	5.89	-	
				Profile V	Puletan loam			
A_1	0-6	0.88	2.54	65	21.26	14.58	6.68	0.68	
A_{21}	8-15	1.32	2.86	54	11.62	7.53	4.09	0.82	
A_{22}	15-30	1.66	2.70	39	7.91	6.10	1.81	0.46	
B_{1t}	30-45	1.33	2.78	52	26.73	23.77	2.96	0.59	2.55
B_{2t}	45-65	1.33	2.48	45	33.02	25.22	7.80	-	
B_{3t}	65-90	1.31	2.43	46	38.17	25.74	10.43	-	
				Profile VI	Puletan loamy sand			
A_1	0-10	1.46	2.57	43	4.88	2.03	2.85	0.44	
A_2	10-25	1.70	2.52	33	4.85	2.69	2.16	0.56	
B_{1g}	25-43	1.68	2.53	34	14.38	11.47	2.91	0.87	
B_{2g}	43-60	1.65	2.57	36	18.82	13.31	5.51	1.55	3.42

TABLE 21--Continued

Hori-zon	Sample depth	Bulk density	Particle density	Total porosity	Moisture retained 1/3 bar	Moisture retained 15 bar	Available moisture storage capacity Horizon	Available moisture storage capacity Upper 80 cm
	cm	g/cc	g/cc	volume %	volume %	volume %	cm	cm
				Broken Pine Ridge				
				Profile VII Granodore sandy clay loam				
A_1	0-16	1.23	2.43	49	13.20	8.63	4.57	1.01
A_2	16-23	1.26	2.59	51	12.10	6.05	6.05	0.39
B_1	23-40	1.43	2.44	41	10.96	6.22	2.74	0.67
B_{2t}	40-66	1.34	2.46	46	30.55	21.54	9.01	2.41	4.48
B_{3t}	66-100	1.31	2.48	47	30.75	23.63	6.85	-
				Profile VIII Silkgrass sandy loam				
A_1	0-15	1.21	2.60	53	8.28	4.61	4.48	0.81
A_2	15-30	1.37	2.64	48	8.60	2.82	2.66	0.55
B_1	30-55	1.51	2.66	43	8.28	2.28	3.01	1.14
B_{21}	55-80	1.62	2.68	40	8.63	1.80	7.13	0.58	3.08
B_{22}	80-124	1.78	2.64	33	10.74	7.15	3.59	-
B_3	124+	1.67	2.66	37	18.86	10.01	8.67	-
				Profile IX Silkgrass sand				
A_1	0-13	1.28	2.54	50	7.64	3.08	4.56	0.76
A_2	13-30	1.46	2.58	43	4.66	2.86	2.00	0.50
B_1	30-52	1.63	2.63	38	8.84	5.02	3.82	1.37
B_{21t}	52-67	1.66	2.62	33	12.76	8.31	4.45	0.60	3.23
B_{22t}	67-83	1.61	2.53	39	28.75	22.06	6.64	-

TABLE 21--Continued

Hori-zon	Sample depth	Bulk density	Particle density	Total porosity	Moisture retained 1/3 bar	Moisture retained 15 bar	Available moisture storage capacity Horizon	Available moisture storage capacity Upper 80 cm
	cm	g/cc	g/cc	volume %	volume %	volume %	cm	cm
Melinda Coastal Pine Ridge								
Profile X: Sirin loamy sand								
A_1	0-13	1.23	2.48	50	10.49	3.65	6.84	1.08	
A_{21}	13-20	1.44	2.61	45	8.18	2.87	5.31	0.54	
A_{22}	20-48	1.48	2.74	43	2.19	1.27	0.92	0.34	
B_{1t}	48-75	1.55	2.55	39	7.89	6.25	1.64	0.38	2.32
B_{2t}	75-88	1.68	2.75	39	8.48	6.27	2.21	-	
Profile XI: Melinda loamy sand								
A_{11}	0-8	1.06	2.72	60	4.70	4.51	0.19	0.01	
A_{12}	8-13	1.26	2.66	53	5.52	4.18	1.34	0.13	
A_2	13-25	1.19	2.64	55	5.08	4.23	0.85	0.12	
B_1	25-55	1.63	2.62	38	13.39	1.62	11.77	5.76	
B_2	55-72	1.74	2.88	33	8.48	2.93	5.55	0.48	6.50
Profile XII: Bacispies loamy sand								
A_1	0-15	1.32	2.56	48	4.84	3.82	1.02	0.20	
A_2	15-30	1.62	2.60	38	12.19	5.88	6.31	1.53	
B_1	30+	1.57	2.75	43	8.15	2.28	5.87	2.78	4.46

TABLE 21--Continued

Hori-zon	Sample depth	Bulk density	Particle density	Total porosity	Moisture retained		Available moisture storage capacity		
					1/3 bar	15 bar	Horizon		Upper 80 cm
	cm	--------g/cc--------		----------------volume %----------------				--------cm--------	
				Mountain Pine Ridge Profile XIII: Pinol gravelly clay (hill soil)					
A_2	0-8	1.39	2.49	44	21.83	15.58	8.25	0.70	
B_{1t}	8-23	1.38	2.48	43	30.54	21.08	9.46	1.97	
B_{2t}	23-47	1.49	2.55	42	31.78	19.84	11.94	4.27	
B_{3t}	47-92	1.58	2.82	38	26.81	17.94	8.87	1.75	8.69
C	92+	Not analyzed							
				Northern Pine Ridge Profile XIV: Tok loamy sand					
A_1	0-13	1.18	2.51	53	9.54	3.25	2.29	0.35	
A_2	13-23	1.47	2.59	43	4.75	0.99	3.78	0.88	
B_{1t}	23-30	1.38	2.64	48	13.41	7.10	8.31	0.81	
B_{2t}	30+	1.39	2.58	48	23.89	12.79	11.23	4.68	9.19

Almost all surface horizons of pine ridge soils are sandy, therefore porosity values of these horizons can be compared with each other. It appeared that the Broken Pine Ridge had the highest average value of total porosity, while the Savanna Pine Ridge had the lowest total porosity in the surface soil (Table 21). Porosities of the subsoils are not comparable among pine ridges, because of textural differences. The variation in porosities among profiles within a pine ridge reflects often the productivity of the site.

Porosity of forest soils vary from 30 to 65% of the total volume (Wilde 1958). Close relationships exist between size of pores and texture. Pore space in sands varies between 35 and 50% and are mostly macropores and in clays it varies from 40 to 60%, consisting mainly of micropores. Comparison of porosity should be made within the same textural class.

Within the same profile the porosity drops with depth. Examination of porosity values for subsoils in the Savanna Pine Ridge shows they have minimum values for clays (40%) or even lower, which is an indication of a high degree of compactness or perhaps cementation.

The porosity characteristics of soils may be important in such processes as water retention, aeration, water transmission, root proliferation and nutrient availability (Voorhees *et al.* 1966).

Relative to lands under cultivation, the porosity of the pine ridge soils is, in general, lower. The better sites in the pine ridge had higher soil porosities than the less fertile ones (Table 21).

The porosity of the pine ridge soils in British Honduras is comparable to soil porosities under other natural vegetations. Schulz (1960) and Heyligers (1963), both working in Surinam, found porosity values of around 44% under rain forests and savannas.

It appears that a pore space of 40% or more is favorable for the growth of *P. caribaea*. Although roots can apparently penetrate more compacted soils, the resulting trees are scrubby. A porosity of 55% is required for optimum growth of corn (Bertrand and Kohnke 1957).

Waterlogging apparently increases soil compactness (Profile I, II, XII, Table 20) as a result of dispersion of soil aggregates and filling of soil pores with silt and clay (Figure 10). From top to bottom in the soil profile, a sudden drop in pore volume occurs near the level of the groundwater.

Texture.--Particle size distribution has been summarized graphically in Figures 11, 12 and 13. Detailed data are also presented in Table 31. In general pine ridge soils have sandy surface horizons and clayey subsoils. The transition from sandy to clayey texture may be gradual as in the Broken Pine Ridge and the Melinda Coastal Pine Ridge or abrupt as in the Savanna Pine Ridge.

The figures show that the Broken Pine Ridge and Melinda Coastal Pine Ridge have deep sandy profiles. In contrast clay is the dominating fraction in the Savanna Pine Ridge, Mountain Pine Ridge and Northern Pine Ridge.

There were no stones on the surface, nor gravel and pebbles in the soils of the lowland pines, as the soils were derived from sea alluvium. Occasionally pebbles were present in the soil of the Broken Pine Ridge and in the Melinda Coastal Pine Ridge, especially those formed on river alluvium. Soil sampled in the Mountain Pine Ridge was stony and high in sedentary gravels and pebbles. It was striking that natural regeneration was more frequent on such soils than on those soils that were poor in these materials (Figure 14). Similar results

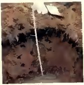
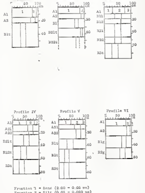
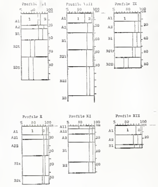


Figure 10.--Shallow profile in the Savanna Pine Ridge
The depth of the water table is only 40 cm.
Note the dark layer is the surface horizon, and the compact subsoil.



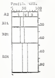
Fraction 1 - Sand (2.00 - 0.05 mm)
Fraction 2 - Silt (0.05 - 0.002 mm)
Fraction 3 - Clay (below 0.002 mm)

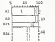
Figure 11.--Graphical representation of particle size distribution, Savanna Pine Ridge (Profile I - VI)



Fraction 1 - Sand (2.00 - 0.05 mm)
Fraction 2 - Silt (0.05 - 0.002 mm)
Fraction 3 - Clay (below 0.002 mm)

Figure 12.--Graphical representation of particle size distribution in soils of Broken Pine Ridge (Profile VII - IX) and Melinda Coastal Pine Ridge (Profile X - XII).





Fraction 1 - Sand (2.00 - 0.05 mm)
Fraction 2 - Silt (0.05 - 0.002 mm)
Fraction 3 - Clay (below 0.002 mm)

Figure 13. Graphical representation of particle size distribution
Mountain Pine Ridge (Profile XIII)
Northern Pine Ridge (Profile XIV)

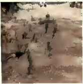


Figure 14.--Gravelly soil in the Mountain Pine Ridge.

were observed by Hanson *et al.* (1965) in Denver, Colorado. They found that on stony soils the vegetation was more mesic and the plants absorbed more nutrients than plants grown in a stoneless medium, even when the medium was richer in these nutrients. They discovered that plants in a stony soil were at a lower moisture tension whereby uptake of minerals was aided.

This study showed that high producing sites for pines corresponded with loamy surface horizons and a deep clay layer. In the Savanna Pine Ridge the clays are located at a very shallow depth in the profile, in poor sites between 20 and 30 cm (Table 31), in the more productive soils it is a little deeper (40 cm). In the Broken Pine Ridge and Melinda Coastal Pine Ridge clayey horizons are deeper than 60 cm under the surface. Growth variations of *P. caribaea* among and within pine ridges are apparently related with texture. It has been reported in recent investigations that texture influences nutrient uptake (Rin'kis and Ramane 1966). Uptake was strongly reduced by replacing sand with finer sand and introduction of kaolinitic clay, according to their observations.

Moisture characteristics.--Results of measurements of water retained at 1/3 and 15 bar, expressed in volume percent are given in Table 21

The data suggested that the variations in soil storage capacity of pine ridge soils were related to climate. Soils in areas with less rain as the Mountain Pine Ridge and Northern Pine Ridge have higher storage capacity than soils in humid areas.

It appears that the higher the organic matter content in the surface soil, the higher the water storage capacity of the soil. The correlation coefficient between both characteristics in the pine ridge soils was found to be 0.82.

The storage capacity (d) of a particular horizon was calculated using the formula by Roe (1950) as follows:

$$d\ (\text{cm}) = P''/100 \times D\ (\text{cm})$$

in which $P''/100$ is the available moisture in volume percent and D is the thickness of the horizon. The value of $P''/100$ depends on texture and bulk density. It is low for sand and clay and for soils with high bulk densities. Trees grown in soils with a high water storage capacity can better resist drought than those grown in soils with a low water-holding capacity.

As shown in Table 21, the available moisture in the upper 60 cm of soil was generally low. The most important reasons for this were probably (a) the high percentage of sand, (b) very compact subsoils, that are either impermeable or hold the water too tight, (c) prevalence of non-expanding clay minerals, with a very low storage capacity.

Charter (1940) reported that in 1939 and 1940 large numbers of pines were killed by drought in the coastal and northern plains and in the Mountain Pine Ridge as well. This widespread death might have occurred at other periods in the past. Mass mortality could possibly have taken place, if the drought period extended beyond the normal three or four months.

The consequence of the low water-holding capacity in a humid area is that in the rainy season inundation in the lowlands and surface run-off on the slopes are more frequent, leading to surface erosion and loss of valuable nutritive materials.

Study of clay minerals.--Results of DTA (Differential Thermal

Analysis) illustrate the influence of climate on distribution of clay types (Table 33). Distribution of clay minerals in British Honduras soils apparently follows climatic patterns postulated by Beavers and Bumkleton (1958).

South British Honduras with a humid climate, has soils in which allophane, kaolinite and halloysite predominate. In soil samples from areas where the rainfall is lower such as the Northern Pine Ridge and Mountain Pine Ridge apparently more montmorillonite was present than 1:1 minerals (Table 33).

From each profile, one DTA curve was selected and illustrated in Figures 15 and 16. The proportional distribution of minerals in each of the horizons was estimated by computation of the area under the curve (Murray and White 1955).

In apparent agreement with Mackenzie (1957), who reported that illite could not be identified by DTA in kaolinite-montmorillonite-illite mixtures, no clearcut peaks were found that would indicate the presence of illites in these samples.

However, appreciable amounts of illite were detected on X-ray diffraction by Krueger (1963) in clay taken from rivers in British Honduras. River clays reflect edaphic and climatic conditions in source areas and are not exposed to weathering processes as soil clays. The climate in the uplands of British Honduras is dry and formation of illites is not impossible. Investigations of Krueger (1963) also showed differences in composition of river clay minerals according to location For example, Rio Hondo which drains the most northern part of British Honduras with a semiarid climate, contained clay high in montmorillonite, while clays collected in southern rivers contained mostly kaolinite.

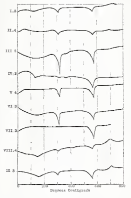


Figure 15.--DTA thermograms of clay from soil samples taken from Savanna Pine Ridge (I - VI) and Broken Pine Ridge (VII - IX)

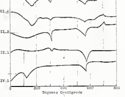


Figure 15.--DTA thermograms of clay from soil samples taken from Melinda Coastal Pine Ridge (X - XII), Mountain Pine Ridge (XIII) and Northern Pine Ridge (XIV).

The Sittee River, which flows through an area with intermediate annual rainfall has clays that are high in illite content.

The following minerals are discussed in sequential order of peaks on the DTA curve, allophane, limonite, lepidocrocite, gibbsite, brucite, kaolinite, halloysite, montmorillonite (Figures 15 and 18)

Allophane.--This clay mineral was found in all profiles in the pine ridge within the forest of Savanna and Melinda, but seemed to be absent in the Mountain and Northern Pine Ridge. This was anticipated because of relatively low annual precipitation. The relative frequencies ranged from fairly abundant to very abundant in the southern coastal pine soils.

Allophanes are amorphous clay minerals for X-ray diffraction, because they lack a regular arrangement of atoms within molecules or within solid structures.

Limonite (Fe_2O_3 H_2O) and gibbsite (γ-Al_2O_3 $3H_2O$).--Limonite and gibbsite are both hydrates of sesquioxides and as both have endothermic peaks close to each other, it is convenient to group them together in the discussion. The analyses gave proof that soils from Savanna (Profile I to VI) had more gibbsite than in those from Melinda (Profile VII to XII). DTA curves on the sample from the Mountain and Northern Pine Ridge did not show the presence of gibbsite.

According to Jackson (1956), the limonite peak is at 300 C, however, a Florida limonite used as reference, showed a peak at 340 C.

There was also disagreement among several authors with regard to the position of the gibbsite peak. According to Finkell and Carlisle (1964) this peak is located between 330 C and 350 C, while Sherman (1958) based his determinations in Hawaii on peaks between 350 C and

340 C. Mackenzie (1957) worked with peaks between 320 C and 330 C. Overlapping of peak areas of the two minerals was probable in these circumstances with the result that they showed up in mixtures under one peak. Brazilian gibbsite used as a reference gave a peak at 340 C. Pure limonite and gibbsite could be diagnosed on the shape of peaks, the former is more or less an equilateral triangle, while the latter approaches an isosceles triangle.

In the identification, the peak at 300 C denoted pure limonite and 340 C was reserved for pure gibbsite. Peaks between the two limits was interpreted as a limonite-gibbsite mixture in proportion given by the relative distance. The shape of the peak was an indication as to which of the two minerals predominated in the mixture.

Sherman (1958), who studied gibbsite-rich soil in Hawaii stated that in areas of lowest rainfall, iron oxides accumulate more rapidly than gibbsite. In areas with a very high rainfall where the soils had impeded drainage, gibbsite clay predominated and eventually was resilicated into kaolin minerals.

Goethite (HFeO$_2$) —Goethite, is the most common naturally occurring crystalline hydrate of ferric oxide. It gives to some soils a brown to yellow color and shows up in DTA curves with a large endothermic peak at 380 C. Only a few samples from profiles with a relatively good soil aeration gave very weak peaks, indicating low contents in this mineral. They are absent in the waterlogged coastal pines of Melinda, as a consequence of the strongly reduced environment.

Lepidocrocite (γ-FeO.OH) —The presence of this mineral could be detected by an endothermic peak at 304 C and an exothermic peak at 508 C. This mineral was scarce and was mainly confined to a few horizons with good aeration, having a yellowish-brown color.

Brucite (Mg (OH)$_2$) --The soils under study were very poor in this mineral, which was understandable as this mineral is formed in an alkaline environment. Brucite is formed from dolomite by the process of complete or incomplete decarbonization (Faust 1948). Presence of brucite was detected on DTA on soil sample from Northern Pine Ridge. The soils in this area are underlain by limestone.

Kaolinite ($Al_2Si_2O_5(OH)_4$) and halloysite ($Al_2Si_2O_5(OH)_4 \cdot 2H_2O$) -- Both clay minerals were represented strongest in the pine ridge soils within the Savanna and Melinda Forest Divisions (Table 33). Most of these soils are probably in the ultimate state of maturity as kaolinite and halloysite are attributes of highly weathered soils.

Interpretation of these minerals on DTA curves was difficult because allophane and halloysite overlapped on water loss in peak A. Both kaolinite and halloysite were common in peak B. Peak D was not observed (Table 32) due to operational conditions of working with a maximum temperature at 850 C. In practice the easiest method of distinction between kaolinite and halloysite is one based on slope ratios (Fiskell and Carlisle 1964).

It is noted from the formula that the Si/Al ratio in kaolinite is lower than in montmorillonite, $(Al_4)(Si_{7.33}Al_{0.87})O_{20}(OH)_4$. Kaolinite and halloysite have been subjected to the process of desilication. In this process, Si is dissolved and remains soluble until excess water drains it away. Large quantities of alkali metals, such as K or Na, are needed for kaolinite formation, along with a low content of Ca or Mg to prevent flocculation of Si, and large amount of water. According to Mohr and Van Baren (1954), complete removal of Si by intensive desilication or laterization could take place only when the soil was permeable and subject to leaching losses. The development as illustrated above possibly took place in the Broken Pine and Mountain Pine Ridge with the formation of reddish soils that are high in sesquioxides.

However, Si is not removed completely in soils of lowland pine ridges because of impermeability of subsoils. This results in intermediate desilication and formation of kaolinitic clay (Jackson 1965). Potassium feldspars, as microcline ($KAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$), weathered to halloysite (Bates 1962).

Allophanes were formed in areas with a concave relief, where desilication proceeded very mildly, due to poor drainage.

Montmorillonite.--Only one horizon in Savanna soils (Profile VI 1) and one in Melinda soils (Profile IX 1) gave indications of some montmorillonite. DTA curve on surface soil sample of the Mountain Pine and Northern Pine Ridge showed peak pointing to the relative abundance of this mineral type. This area has a semi-arid climate having soils containing relatively large amounts of Si, Fe, Al, Mg, Ca and Na.

Hydrolysis of Si occurs when the soil is wet and Si is not removed because of poor internal drainage. In the dry season the soil solution becomes saturated with bases and Si on drying, so that montmorillonitic clay develops (Keller 1964).

Unidentified peaks.--An exothermic peak around 700 C was found on many of the DTA curves which could not be identified by consulting available literature.

Many properties of the soils, such as water holding capacity and cation-exchange capacity, are largely explained by the distribution of clay minerals in the soils. Katamorphism of primary minerals in the lowland pine ridge is probably intense because of the abundant moisture supply, high temperature, and rapid mineralization of organic matter

(De Villiers 1965). Characteristics of the British Honduras pine ridge soils are: the occurrence of resistant primary minerals as indicated by the high content of quartz sands on the surface, clay accumulation in the subsoil, predomination of 1:1 layer lattice types (kandites), represented by kaolinite, halloysite and allophane. Montmorillonite is mainly confined to the Mountain Pine and Northern Pine Ridge. Red and orange mottling was common because of transportation of iron oxides by downward movement of acidic soil water.

The results of this study should be considered as preliminary, and must be verified with other methods of identification. Sen and Chatterjee (1967) suggested that any conclusion on the mineralogical make-up of silt or clay samples arrived at by any single measurement may often be erroneous and that identification and estimation of clay minerals present should be made by a combination of several measurements.

Climate

From weather data supplied by the Department of Forestry and Department of Agriculture of British Honduras, it was clear that P. caribaea grows naturally in areas with at least 1,500 mm annual precipitation. Data on annual precipitation was obtained for Belize Airport and Maskall, representing Northern Pine Ridge, Melinda, representing Belinda Coastal Pine Ridge and Broken Pine Ridge, Savanna, representing Savanna Pine Ridge, Augustine, representing Mountain Pine Ridge.

Temperature data were available only from Melinda, Savanna and Augustine. Precipitation is unevenly distributed. There is a long dry season from February to April and a short one in August, and the wet season from June to October (Table 34, Figure 17).

The maximum temperature is about 35 C in both low and upland, the

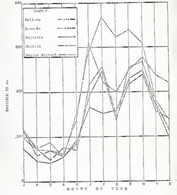


Figure 17.--Monthly precipitation of some selected stations within the pine belt in British Honduras (compiled from data collected by the Forest Department and Department of Agriculture of British Honduras)

temperature in the lowlands does not go lower than 14 C, and in the Mountain Pine Ridge 8 C is the minimum temperature of the year (Figure 18, Table 34).

Several classifications could be applied to characterize the climate of British Honduras.

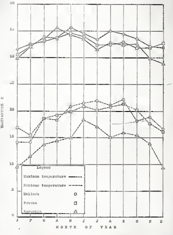
Koppens classification.--Distribution of *P. caribaea* in the lowlands is restricted to areas with a tropical rainy climate (A- climate in the Koppens classification, Appendix III). This climate is defined by an average annual temperature between 20 and 25 C and an annual rainfall higher than 700 cm (Mohr and Van Baren 1954). Distinction should be made between the climates of Savanna Pine Ridge, Broken Pine Ridge and Melinda Coastal Pine Ridge on one side and that of the Northern Pine Ridge on the other. The first is designated in the classification as Af- climate (tropical wet climate) and the latter as Am climate (monsoon climate with moderate dry periods). The most northern part of British Honduras where *P. caribaea* does not occur naturally, is likely to have Aw^1 climate (tropical savanna climate with rainfall maximum in autumn).

Based on temperature and rainfall, *P. caribaea* in the Mountain Pine Ridge grows in a climate close to Cw climate (Appendix III) where the average temperature in December and January is probably lower than 18 C.

Based on maximum rainfall in the driest month (Mohr and Van Baren 1954), it appears that *P. caribaea* does not grow naturally in a tropical savanna climate as classified by Koppen (Trewartha 1954), although the occurrence of pines in Central America is associated with a savanna type vegetation.

This is in contradiction to what was claimed by Luckhoff (1964)

Figure 18.--Monthly minimum and maximum temperature of some selected stations within the pine belt in British Honduras (compiled from data collected by the British Honduras Forest Department).


40
35
30
25
20
15
10
5
0
TEMPERATURE C
Legend
Maximum temperature
Minimum temperature
Melinda ○
Savana □
Agustin △
J
F
M
A
M
J
J
A
S
O
N
D
MONTH OF YEAR

Richards (1964) was probably correct to oppose the use of the term "tropical savanna climate", because of the confusion it caused.

Holdridge classification.--According to the Holdridge classification (1947), which is widely used in Central America, P. caribaea var. hondurensis grows in three natural life zones, namely in tropical moist forest, tropical dry forest and lower montane (subtropical) life zone. Use of this classification to characterize the climatic conditions for the growth of this pine creates problems, because part of the two latter life zones have an annual rainfall lower than the tolerable limit for the species (1,500 mm)

Thornthwaite classification.--Temperature and rainfall data from selected stations within and outside the pine belt were sent to the Laboratory of Climatology in Elmer, N. J. for computation of water balance data. They are presented in Table 35. From this information climatic data for the stations were compiled (Table 22). They suggest that P. caribaea in natural stands in British Honduras grows under humid or moist sub-humid megathermal climates, i.e. $B_1Aa'r$, $B_2Aa'r$ and $C_2Aa'r$ climatic types according to the criteria proposed by Thornthwaite (1948). The species does not grow in a dry sub-humid or a drier climate (semi-arid and arid). The stations within the pine area have an annual water surplus between 113 and 942 mm, which occurs from June to January in Savanna and Melinda, and from September to February at the other stations. The surplus at stations outside the pine belt is much lower (0 to 57 mm). The total annual deficit within the pine belt ranges between 32 to 82 mm, which occurs from March through May. The deficit in areas outside the pine belt is much higher (136 to 159 mm). Deficit and surplus are shown digrammatically for four stations (Figures 19 and 20) by tracing the balance between precipitation and potential evapotranspiration or water need throughout the year.

TABLE 22

COMPARATIVE WATER BALANCE DATA AT SELECTED STATIONS IN BRITISH HONDURAS

Station	Potential evapotranspiration	Summer concentration	Precipitation	Moisture surplus	Moisture deficit	Indices of Humidity	Indices of Aridity	Indices of Moisture	Climatic type
	-- mm ---	--%--	----------	mm	----------				
				Within pine belt area					
Savanna	1620	30	2430	642	32	61.97	2.10	59.87	B_2Aa'r
Melinda	1571	31	2156	626	41	39.85	2.61	38.85	B_1Aa'r
Augustin	1163	32	1532	420	41	36.43	3.56	32.87	B_1Aa'r
Maskall	1478	33	1772	363	69	24.56	4.67	19.89	C_2Aa'r
Belize Airport	1476	32	1743	336	67	22.87	4.53	18.33	C_2Aa'r
Orange Walk	1478	32	1509	113	82	7.65	5.56	2.09	C_2Aa'r
				Outside pine belt area					
Louisville	1476	32	1340	0	138	0	9.34	-9.34	C_1Aa'd
Corozal Town	1475	32	1316	0	159	0	10.76	-10.76	C_1Aa'd
El Cayo	1478	32	1388	57	136	3.86	9.20	-5.34	C_1Aa's

Figure 19.--Balance between precipitation and potential evapotranspiration of Melinda (Melinda Coastal Pine Ridge and Broken Pine Ridge) and Savanna (Savanna Pine Ridge).

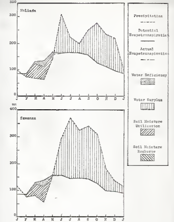
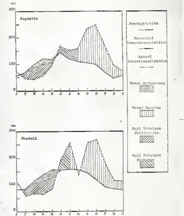

mm
350
300
200
100
0
Malinda
J F M A M J J A S O N D J
mm
400
300
200
100
0
Savanna
J F M A M J J A S O N D J
Precipitation
Potential Evapotranspiratio
Actual Evapotranspiratio
Water Deficiency
Water Surplus
Soil Moisture Utilization
Soil Moisture Recharge

Figure 20.--Balance between precipitation and potential evapotranspiration of Augustin (Mountain Pine Ridge) and Maskall (Northern Pine Ridge).


mm
300
Augustie
200
100
0
J F M A M J J A S O N D J
mm
300
Haskell
200
100
0
J F M A M J J A S O N D J
Precipitation
Potential Evapotranspiration
Actual Evapotranspiration
Water Deficiency
Water Surplus
Soil Moisture Utilization
Soil Moisture Recharge

Effect of climate on soil and growth of P. caribaea.--The humid and warm climate prevailing in the pine belt affects soil and pine growth. Under such a climate breakdown of minerals, litter and humus are intensified. Rate of leaching and erosion are much higher in the pine area than in the area outside, flooding and waterlogging conditions are very frequent resulting in poor soil aeration.

Although the moisture deficit is relatively small, it may become critical for growth of *P. caribaea*, because of the low water storage capacity of pine ridge soils. The subsoils become stone hard and impenetrable to pine roots when dry. Most likely pines are dormant during this dry period as happens during the winter in temperate zones.

Poor aeration in pine ridge soils on flat and concave topography may check the growth rate of pines in the rainy season. The water deficit and surplus shorten the effective growth period of pines in the lowland savannas, probably one of the reasons for the very slow growth. These unfavorable conditions are not present for pines growing on slopes such as in the Broken Pine Ridge and Mountain Pine Ridge, and along creeks and rivers where drainage is usually good.

Growth conditions in the Northern Pine Ridge are better than in Savanna and Melinda, in spite of its flat topography, because of the lower water surplus.

Growth Measurements in British Honduras

In the late fifties the Forest Department of British Honduras laid out a series of experimental plots in the Savanna, Melinda and Augustine Forest Division, to obtain a better understanding of growth requirements of *P. caribaea*. The nature of these experiments varied from place to place with treatments designed to solve local problems. Trees were measured at regular intervals and data recorded by trained personnel.

In large part, the results of these experiments are not compiled nor published. The author was given the opportunity to interview the forest guard-in-charge, visit the experimental plots, study the field plot and use the data for background information for his study. Preliminary results of the experiments were included in the dissertation because they help explain growth of P. caribaea observed in the field as well as in the greenhouse experiment.

Savanna Pine Ridge.—Two types of experiments were in this District, they included fertilization and regeneration experiments and increment plots. These plots were visited and records of periodical growth measurements were studied.

1. Fertilization experiment in 1958 plantation.

Soil characteristics: The soil had a sandy surface and the drainage was poor.

Treatments: 0, 14, 28 or 56 g of superphosphate were applied in a circle around each individual tree at the time of planting (this is equivalent to approximately 0, 24, 48 and 96 kg/ha).

Results: Measurements of trees in 1962 and 1963 produced the following results:

Superphosphate applied tree	Average height 1962	Average height 1963	Mean annual increment 1962	Mean annual increment 1963
g	m			
0	2.85	3.35	0.43	0.48
14	3.76	4.39	0.63	0.63
28	4.17	4.85	0.70	0.68
56	4.43	5.24	0.74	0.74

Discussion: There were substantial growth increases associated with applications of superphosphate, but the increments were proportionally lower at the higher rates. Residual effects of P still remained after the seventh year, even at the low rate of 14 g per tree. A marked increase of growth in control plots was also noted. It is probable that soil conditions gradually improved with time in the absence of such disturbing factors as fires.

3 Fertilization experiment in 1954 plantation This experiment was designed to find out whether repetition of fertilizer application was necessary.

Soil characteristics The soil had a sandy loam texture on flat topography

Treatments. All trees were fertilized at time of planting with 56 g of superphosphate. Additional applications were made as follows:

A 56 g superphosphate in 1956.

B 56 g superphosphate in 1958 and 1962.

C. 56 g superphosphate in 1958 and 1962 and planned for 1966.

D Control, fertilized only at planting in 1954.

Results: Performance of seedlings was assessed in 1962 with the following results:

Year of reapplication	Average height	DBH	Mean annual increment Height	Mean annual increment DBH
	m	cm	m	cm
1954, 1958	6.25	11.6	0.78	1.6
1954, 1958, 1962	6.16	12.0	0.77	1.5
1954, 1958, 1962, (1966)	6.16	11.6	0.77	1.4
1954 only	6.07	11.2	0.75	1.4

Discussion. The 56 g application of superphosphate given to all plots at planting had boosted growth sufficiently that even after eight years there was little difference in tree diameters of those that were fertilized only once and those that were refertilized. Repetition of fertilizer application at four year intervals was unnecessary. The basic treatment in this experiment was similar to the highest treatment of experiment 1 and no effect of the texture was apparent.

3. Fertilization experiment in 1956 plantation. In this experiment fertilizers were applied at 0 to 6 months after planting.

Soil characteristics: The site had a heavy clay subsoil.

Treatments. 56 g of superphosphate were applied broadcast around each tree at planting, 3 months after planting, 6 months after planting, and control (not fertilized).

Results. Measurements made in 1962 resulted in following figures:

Time of application	Average height	Mean annual increment
	m	
At planting	3.88	0.65
3 mo. after planting	3.88	0.61
6 mo. after planting	3.16	0.63
No application	2.89	0.44

Discussion. It appeared that superphosphate applied at planting time resulted in better growth than did later applications. The nonfertilized trees of this experiment made about the same growth as nonfertilized trees of experiment 1, in sandy soil. All fertilized trees regardless of time of application grew better than nonfertilized trees. However the response to superphosphate in this fine textured soil was not as great as on the sandy soil.

4. Site preparation experiment 1977. The purpose of the experiment was to find the best method to assist natural regeneration.

Soil characteristics. The soil had a coarse textured surface soil, covered with a 5 cm thick humus layer. The subsoil was heavy clay.

Treatments:

A. Rotavated strips made at 3 m intervals and drained at 20 m intervals. The soil was disc ridged. Pine seed was distributed with a corn planter.

B. Same as A, except the soil was not disc ridged.

C. Same as A, but the area was left for natural regeneration.

D. Drains were made at 20 m intervals and the area left for natural regeneration.

Results. Tree performance was assessed in 1980 and 1982 with the following results:

Site treatment	Trees/ha 1980	Trees/ha 1982	Percent of full stocking at 3 x 3 m 1980	Percent of full stocking at 3 x 3 m 1982	Average height 1982	Mean annual increment height 1982
	No.		%		m	
A. Rotavated, drained, ridged and planted	260	414	24	37	0.51	0.10
B. Rotavated, drained, and planted	201	331	18	30	0.47	0.09
C. Rotavated, drained, and ridged; naturally regenerated	131	275	12	25	0.48	0.10
D. Drained only; naturally regenerated	88	214	8	19	0.47	0.09

Discussion. There was a general increase in stocking, which in the plots left for natural regeneration amounted to more than twice the number of trees found in 1982 as in 1980. After five years no treatment was sufficiently satisfactory to warrant the cost of the preparation treatments because growth was so very poor without fertilization.

5. Fertilizer application to natural regeneration.

Soil characteristics. The soil of the site had a sandy surface horizon with 6 cm humus layer covered and overlying a clayey subsoil.

Treatment. The natural regeneration was approximately two years old at time of treatment. The plots were given the following treatments:

A Control (no fertilizers).

B. Superphosphate applied by machine spreader at a rate of 84 kg per hectare.

C. Fertilized as in B and drained as required.

D Drained as required without fertilization.

Results. The trees were measured in 1958 and 1962 and the following results were obtained:

	Treatment		Average height		Mean annual increment
	Drained	Fertilized	1958	1962	height
			m		
A	-	-	0.55	2.35	0.36
B.	-	+	0.67	3.36	0.54
C.	+	+	0.50	3.06	0.52
D	+	-	0.59	2.71	0.42

Discussion. It appeared that drainage improved tree growth about 16% over that in undrained soil in the absence of fertilizers. Fertilizers increased growth by about 50% over that obtained without the superphosphate. Furthermore, drained fertilized soil did not produce larger trees than undrained fertilized soils.

6. Provenance studies and response to fertilization.

Soil characteristics: The plot had a sandy surface soil with a heavy clayey subsoil.

Treatments: The following provenances were tested:

A. Coastal pine from Stann Creek.

B. Upland pine from Augustin.

C. Coastal pine from Mango Creek.

Groups of seeds were sown in 1957 at 3 m x 3 m, six in a group. The soil was fertilized either before or after sowing.

Results. Trees were measured in 1963 with the following results:

	Height			Mean annual increment		
Fertilization	Stann Creek	Augustin	Mango Creek	Stann Creek	Augustin	Mango Creek
	m					
Before planting	1.86	1.59	1.71	0.31	0.25	0.11
After planting	1.58	1.74	1.71	0.26	0.29	0.20
None	0.64	1.22	0.75	0.11	0.28	0.12

Discussion: Rate of fertilizer application is not known. In unfertilized soil upland pines showed a better growth than the two lowland types, but the latter responded more to fertilization. All strains responded to P fertilization when planted in the Savanna Pine Ridge.

7. Determination of the best rate of fertilizer application.

Soil Characteristics: The soil had a thick humus layer in surface horizon.

Treatments: Trees were planted in 1958 and each was given the following doses of superphosphate: A. 28 g; B. 14 g; C. 7 g, D. none.

Results: Measurements in 1963 on five year old trees gave the following results:

Superphosphate applied	Average height	DBH	Mean annual increment	
			Height	DBH
g/tree	m	cm	m	cm
28	3.23	7.5	0.65	1.5
14	2.93	7.7	0.59	1.5
7	2.84	6.9	0.57	1.4
0	2.28	5.7	0.46	1.1

Discussion: Diameter, height and consequently volume growth increased with increasing rates of superphosphate. This experiment did not lead to conclusions about the maximum rate beyond which growth decreased.

Increment studies: There were nine increment plots established in the Savanna Pine Ridge, mainly concentrated near Mango Creek. They are designated with MC 1 to 9. One of them was laid out in natural regeneration and no measurements records were available from this plot and from three other plots. Only five plots are discussed in which the exact ages of the trees are known. On one of these sites no information could be found on size of plot, so that the volume growth per hectare was not estimated.

The characteristics of the soil within each plot, as recorded in the archives is below:

Plot	Soil	Slope	Drainage	Vegetation
MC 3	Riverine alluvium	Level	Good	Creekside vegetation
MC 4	Thin humus layer, gray sandy surface soil with 20 cm yellow crumbly clay	Level	Poor (mottling red)	Sparse pine formation
MC 5	As MC 4	Gentle	Poor	Sparse pine formation

Plot	Soil	Slope	Drainage	Vegetation
MC 6	Dark peaty deposit with fine grey sand overlying hard white pan (fertilized with 28 g superphosphate per tree).	Level	Poor	Open savanna
MC 7	Sandy loam	Level	-	Pine forest

Results. The results are given in Table 23.

Discussion. The conditions for growth of pine are best along the creeks (MC 3) where the soil is relatively more fertile than in the savanna. Trees responded to fertilization (MC 6), yet the increment rate was still low. Growth of trees was much better on sandy loam than on soils rich in clay. The natural vegetation on the site is a fairly reliable indicator of soil fertility as related to pine growth. Drainage seemed to play a very prominent role.

Broken Pine Ridge.—Twenty-one increment plots were laid out in the plantations within the Grante Work Reserve of the Broken Pine Ridge until 1961. All plots were severely damaged by hurricane 'Hattie' in 1961. Many trees in the plots were blown down and calculations on growth based on tree measurements after that year do not reflect the growth potentials of the site.

Soils within these increment plots did not differ greatly and were characterized as coastal deposits of 30-38 cm brown sandy loam over yellow brown sand and clay with little humus.

The size of the increment plots are 0.04 ha each. The results are given in Table 24.

TABLE 23

GROWTH MEASUREMENTS IN INCREMENT PLOTS IN THE SAVANNA PINE RIDGE

No.	Year of planting	Year of measurement	Age	Trees per ha	Average Height	Average DBH	Volume per ha	Mean annual increment Height	Mean annual increment DBH	Mean annual increment Volume
			year	no.	m	cm	m^3	m	cm	m^3
MC 3	1949	1964	15	375	12.20	18.1	90.64	0.81	1.3	6.04
MC 4	1950	1964	14	855	4.59	8.7	10.58	0.33	0.6	0.76
MC 5	1951	1963	12	1,190	2.62	6.4	5.64	0.22	0.5	0.47
MC 6	1953	1963	10	625	4.71	13.3	40.79	0.44	1.3	4.08
MC 7	1954	1964	10	–	5.31	11.6	–	0.53	1.2	–

TABLE 24

GROWTH MEASUREMENTS IN INCREMENT PLOTS IN THE BROKEN PINE RIDGE

No.	Year of planting	Year of measurement	Age	Trees per ha	Average Height	Average DBH	Volume per ha	Mean annual increment Height	Mean annual increment DBH	Mean annual increment Volume per ha	Top height
			Year	no.	m	cm	m³	m	cm	m³	m
GWR 3	1944	1961	17	800	15.06	18.4	252	0.88	1.1	14.8	-
4	1945	1961	16	600	16.31	16.0	243	1.02	1.0	15.2	16.53
5	1948	1961	13	625	11.01	18.7	175	0.85	1.4	13.5	14.00
7	1946	1961	15	1,150	14.15	17.7	281	0.94	1.2	18.7	15.90
8	1946	1961	15	1,125	13.91	17.0	248	0.93	1.1	16.6	-
9	1946	1961	15	825	14.10	19.1	263	0.94	1.3	17.5	15.82
10	1944	1961	17	750	13.27	16.3	145	0.78	1.0	8.5	14.03
11	1945	1961	16	700	12.44	16.1	124	0.77	1.0	7.8	14.09
12	1946	1961	15	700	13.11	17.7	158	0.87	1.2	10.5	13.16
13	1947	1961	14	700	13.60	19.2	207	0.97	1.4	14.8	14.70
14	1948	1961	13	775	13.42	18.8	224	1.03	1.5	17.2	15.13
15	1949	1961	12	800	11.59	20.7	164	0.97	1.7	13.7	13.30
16	1950	1961	11	850	15.13	21.3	245	1.37	1.8	22.3	16.83
17	1951	1961	10	675	11.04	18.0	133	1.10	1.8	13.3	12.26
18	1952	1961	9	550	8.54	15.0	58	0.95	1.7	6.4	9.76
19	1953	1961	8	800	9.82	16.6	123	1.22	2.1	15.3	11.16
20	1953	1961	8	750	8.17	13.5	62	1.02	1.7	7.8	9.76
21	1953	1961	8	750	9.64	15.7	98	1.20	2.0	12.2	11.41

Discussion: Mean annual increment of volume per hectare ranged from 6.4 to 22.2 m^3. The results establish the assumption that the soils of the Broken Pine Ridge are the most productive among all pine woodland soils in British Honduras. Tree growth here is much higher than in the Savanna Pine Ridge, even when the latter soils were fertilized. Differences in productivity between increment plots are undoubtedly related to conditions of soils. No detailed information was available on soils in each plot, so that little can be concluded regarding the soil factors governing pine growth, except as discussed previously.

Mountain Pine Ridge.--Five 0.04 ha sites were selected in the Mountain Pine Ridge for plots dealing with fertilization of natural regeneration, at each site, one half was given 56 kg/ha of superphosphate in broadcast application and the other half was unfertilized. Every year trees were counted and classified in height classes at 30 cm intervals.

All plots had essentially the same soil characteristics. Records gave only the following information for all plots. Granite parent material, with sandy loam over clay over granite. Humus was negligible and tended to be raw

The main differences among sites were the slopes and aspect of the terrain. The sites were designated as follows

E 1 had a gentle slope and south aspect

E 2 had a gentle slope and southwest aspect

E 3 had a gentle slope and southeast aspect

E 4 was flat and wet

E 5 was flat but not wet

The results of the tests are presented in Table 25.

TABLE 28

GROWTH MEASUREMENTS IN FERTILIZED AND UNFERTILIZED NATURAL REGENERATION OF P. caribaea IN THE MOUNTAIN PINE RIDGE

				1958				1962				Mean annual increment			
				Control		Fertilized[1]		Control		Fertilized[1]		Trees		Height	
Plot	Slope	Aspect	Drainage	Trees per ha	Average height	Trees per ha	Average height	Trees per ha	Average height	Trees per ha	Average height	Control	Fertilized	Control	Fertilized
				No.	m	No.	m	No	m	No	m	No		cm	
E 1	Gentle	South	-	1,350	0.85	3,225	0.52	1,800	1.56	4,400	2.11	180	392	30.3	43.0
E 2	Gentle	Southwest	-	3,400	0.89	8,750	0.85	3,828	1.75	5,550	1.84	142	297	28.7	33.0
E 3	Gentle	Southeast	-	4,450	0.59	3,275	0.68	3,325	1.53	2,650	1.60	-375	-108	31.3	30.3
E 4	Flat	-	Poor	1,750	0.48	2,250	0.66	1,600	1.43	3,100	1.51	50	283	31.3	28.3
E 5	Flat	-	Good	2,025	1.55	1,475	1.13	2,475	2.85	1,875	2.82	150	33	43.3	56.3

---

[1] Fertilized with superphosphate at the rate of 58 kg/ha

Discussion: The best growth, whether fertilized or not occurred on the flat, well drained site (E 6). No big differences were noted in growth among the other four plots in unfertilized conditions. When fertilized, trees with a south aspect (E 1) made the best response, and those on the flat wet sites made the poorest growth. The poor growth on the latter site was perhaps due to drainage. Table 26 also shows variations in growth among fertilized sites with south (E 1), southwest (E 2) and southeast (E 3) aspect. The available information was not adequate to draw conclusions on the possible reason for these differences.

Greenhouse Experiments

Effects of Treatments on Soil Chemical Properties

Soil pH

The average pH in the wet soils was 5.8 and that in the drained soils was 5.6 (Table 36). The effect of high water table treatments on the increase of pH was highly significant (Table 26). This increase may have been caused by dissolution of cations either from the exchange complex or from the crystal lattice. There was also an increased solubility of Fe and Al, which hydrolyzed to give higher pH values under reduced conditions.

Nitrogen significantly reduced pH (Table 26), particularly in drained soil (Table 36, Figure 21, I and II). The NO_3-N component was mainly responsible for the acidification.

Phosphorus significantly increased pH (Table 26), particularly in wet soil (Table 36, Figure 21, III and IV), the associated Na ion in the salt was the cause of this effect.

The interaction between water treatment and N was significant

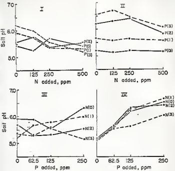
TABLE 28

ANALYSIS OF VARIANCE FOR EFFECTS OF WATER TREATMENTS, N AND P ADDITIONS ON SOIL pH, RESIDUAL TOTAL N, EXTRACTABLE P AND K

Source	Degrees of freedom	Soil pH		Residual Total N		Residual extractable P		Residual extractable K	
		Mean squares	F	Mean squares	F	Mean squares	F	Mean squares	F
Replications	3	0.02	0.66	0.10	0.39	12.74	5.86	4.18	0.57
Treatments	31								
Water (W)	1	1.65	55.00^1	0.74	2.87	1,746.08	80.78^1	2.43	0.33
Nitrogen (N)	3	0.70	21.21^1	5.27	20.43^1	117.64	5.46^1	2.68	0.37
Phosphorus (P)	3	2.67	80.91^1	0.67	3.76^2	2,621.32	121.28^1	25.73	3.51^2
W x N	3	0.10	3.36^2	1.60	6.20^1	67.33	3.11^2	71.70	8.74^1
W x P	3	1.20	36.36^1	1.00	3.81^2	316.14	14.72^1	11.06	1.50
N x P	9	0.18	5.75^1	0.54	8.09^2	66.55	2.87^2	60.14	8.17^1
W x N x P	9	0.14	4.24^1	1.06	4.10^1	55.86	2.58^2	8.53	1.16
Error	62	0.03		0.26		21.62		7.38	

[1] Significant at the 1% level

[2] Significant at the 5% level.



A. Drained Soil

B. Wet Soil

Figure 21.--Effects of water treatments, N and P additions on soil pH.

(Table 26). The pH reduction by N in the wet pots was less than in the drained pots. For example the average effect of 125 ppm of N was a pH of 5.6 in the wet soil and 5.7 in the drained soil (Table 36).

The interaction between water treatment and P was highly significant. It appeared that when no P was applied water treatment suppressed pH, at 62.5 ppm P, water had no effect, while at 125 and 250 ppm P, pH was increased by the presence of water (Table 36, Figure 21, I and II).

Nitrogen reduced the effect of P on soil pH and P had the same effect on N, which was illustrated in the analysis of variance by a highly significant N x P interaction (Table 26, Figure 21).

The interaction W x N x P was also highly significant (Table 26).

Total N

All soils were very low in total N with an average of only 470 ppm in the untreated soils. On the average there was slightly more residual soil N under wet conditions (413 ppm) than under drained conditions (395 ppm) (Table 36). This was surprising because of the possible loss of N through denitrification in wet soils (Skyring and Callow 1962).

Some agent may have contributed N to the saturated soils, as total N in these treatments did not drop below the levels in the drained soils. A dark greenish layer developed on the soil with a high water table. This growth was identified as blue-green algae, Phormidium autumnale[1]. This species is commonly found in salt marshes (Chapman 1962), an environment similar to the site in British Honduras from which soils were collected for the greenhouse experiment. Growth of blue-green algae in the greenhouse was possibly stimulated by the high content of Na in the soil (Allen and Arnon 1955) and by the applied N. The presence of this algae was not ascribed to contamination in the greenhouse, even though the soils had been fumigated at the quarantine station. Algae were also present in the drained pots, however they did not develop so well as in the wet soils. Members of this group have been known to have the capacity for non-symbiotic fixation of appreciable amounts of N in rice paddies (Stewart 1967). The average increase in total N in soils to which no fertilizer N was added was 12 ppm in drained soils and 22 ppm in wet soils.

---

[1] Identified by J. S. Davis, Department of Botany, University of Florida

In most pots residual N at the end of the experiment was higher than in the original soil (330 ppm), even where no N was added, and despite nutrient withdrawal by seedlings and possible loss by leaching and denitrification.

Additions of N significantly increased residual N in pots (Table 26), particularly those with wet soils (Table 36, Figure 22, II). In drained pots however a consistent increase was only present when applied up to 125 ppm, the effect of higher rates was not consistent (Figure 22, I). The effect of N was reduced when applied with P

The effect of added P on residual N was significant (Table 26), especially in drained soil, but the effect varied with rates of P. For instance on the average increasing the P rate from 0 to 62.5 ppm resulted in a decrease of residual total N, when applied with 0 N, 125 ppm N and 250 ppm N, but resulted in an increase when applied with 500 ppm N. An opposite effect was noted when rate of P increased from 62.5 to 125 ppm. Residual total N was reduced when more than 125 ppm P was added. In wet soils P additions practically did not affect the amount of residual N (Figure 22, IV).

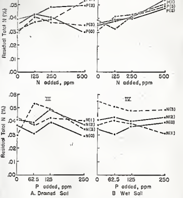


Figure 22 --Effects of water treatments, N and P additions on residual total N

Residual extractable P

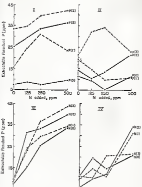
The average content of extractable P in soil used for the greenhouse experiment was 8 ppm before treatments were applied; this is considered to be a low level for tree growth (Wilde 1958, Pritchett 1958). By the conclusion of the experiment, this amount had not changed appreciably in the unfertilized pots (Table 36).

The effect of water treatments was highly significant (Table 26). The average amount of residual extractable P in wet soil was 17 ppm and 25 ppm in the drained soil (Table 36, Figure 23). More P was removed in wet pots, because of more vigorous growth of seedlings in these pots. If P is a limiting factor for tree growth, as indicated by the response to this nutrient, then more P must have become available in wet soils than in drained soils. Saturation increased soil pH which apparently reduced P fixation and resulted in higher P availability as indicated in the analysis of variance (Table 26).

Table 36 shows that residual P increased significantly with increasing doses of NH_4NO_3 in the drained pots (Figure 23, I). Acidity produced by the added N could not account for this increase in extractable P, as fixation would probably have resulted from greater solubility of Fe and Al. On the other hand, it is likely that the more N applied the more intense the anionic competition between NO_3^- and $H_2PO_4^-$ and the lower the amount of P adsorbed.

The effect of N additions on residual extractable P was not consistent in the wet soils (Table 36, Figure 23, II).

It is obvious that residual P increased with increasing P additions in both drained and wet soil (Figure 23, III and IV). Lower values for wet soil than for drained soils were the result of greater removal by



A. Drained Soil

B. Wet Soil

Figure 23.--Effects of water treatments, N and P additions on extractable residual P the fast growing seedlings in former soils.

The W x N interaction was significant, it appeared that in the presence of much water the effect of N was reduced. Soils that received 300 ppm N and 125 ppm P had 24 ppm extractable P at the close of the experiment when the soil was drained, but only 11 ppm when the soil was wet (Table 36)

The W x P interaction was also significant (Table 26)

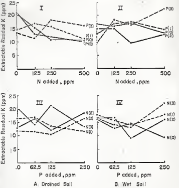
Figure 23, I, shows that in drained soils, the more P was applied with N, the higher the amount of residual extractable P The same tendency was present, when more N was applied with a constant rate of P (Figure 23, III).

Residual extractable K

The average amount of extractable K remaining in pots at the close of the experiment was about the same under drained and saturated conditions (Table 36). However, there was a noticeable reduction from the original level of 42 ppm This reduction may be a temporary one if the soil has a K reserve in primary minerals that can be used to replenish that removed by the tree crop. In most soils an equilibrium exists between slowly available K, exchangeable K, and watersoluble K (Tisdale and Nelson 1987). The rate of replacement of plant absorbed K is very important for plant growth If it is too slow, the development of a deficiency is unavoidable.

The effect of N treatments on residual K was inconsistent (Figure 24).

The effect of P additions on extractable K was statistically significant at the 5% level (Table 26). There appeared to be no difference between the two soil moisture treatments in relation to the effect of added P on extractable K. In both series of water treatments, more K



A. Drained Soil

B. Wet Soil

Figure 24.--Effects of water treatments, N and P additions on extractable residual K.

was left in soils that received no added P and in soils that were fertilized with the highest rate of P (250 ppm P), than from the soils that received the two intermediate rates of P (Table 36). The reason for this quadratic effect is the greater growth rate at the 62.5 ppm and 125 ppm than at 0 and 250 ppm P.

Growth Response to Soil Water Levels and Nutrient Supply

Top and root growth of seedlings, as represented by elongation, diameter, and dry weights of tops and roots were influenced to varying degrees by conditions of soil moisture and available supplies of N and P (Table 37).

Surprisingly, seedlings in pots with a high water table on the average showed a better growth than in drained pots, as summarized below:

Nature of growth	Drained soil	Wet soil
Elongation, cm	18.85	23.32
Diameter, mm	3.04	3.63
Dry weight of top, g	2.14	3.46
Dry weight of root, g	0.70	0.82

These results support the premise that *P. caribaea* seedlings tolerate a high groundwater table, at least for relatively short periods such as covered by this experiment, and apparently are not injured by a low oxygen supply. It is likely that optimum depth of water table increases as seedlings become taller and more root space is needed. Several factors could be responsible for the poorer growth of seedlings in drained pots. One is nutrient leaching, which possibly took place in drained pots. The pots were watered once every three days with 250 ml of distilled water and some loss of water and N may have occurred.

Ammonium nitrate is known to leach very readily. Undoubtedly a large percentage of applied elements moved downward in the saturated pots, but they were not lost to the plants in this closed system. However soil saturation appeared to be harmful to seedlings given 250 ppm of P and 500 ppm of N simultaneously. This treatment resulted in poor growth and even mortality (Figure 25). In drained pots this high level of nutrients was not injurious to plants (Figure 26). In fact the tallest seedlings in drained soils were produced at the high rate of nutrient application.

Nitrogen tended to increase height of seedlings in drained and wet pots, which was significant according to analysis of variance (Table 27). The effect of N was on the average 38% greater in wet than in drained soils. In wet soils however this effect was maximum, when N was given at the rate of 125 ppm (Figure 27, I and II). Growth of seedlings was suppressed at the higher N rates. Elongation at 125 ppm N was 33 cm, but was 27 cm at 250 ppm and only 15 cm at 500 ppm N.

Stem diameter and dry weight of tops increased with increasing N up to 125 ppm, but declined at the 500 ppm rate under both soil moisture regimes (Figures 28, I and II; 29, I and II).

Nitrogen significantly affected root growth (Table 27). Nitrogen appeared to suppress root growth when applied at increasing doses in drained soils (Figures 30, I and 31). In wet soils root weight increased when N was applied at 125 ppm. A further increase of N to 250 ppm, dropped the weight to that of the zero level of N and the weight was halved when the N rate was raised to 500 ppm (Table 27, Figure 30, II).

The effect of P was highly significant on all parameters of top growth (elongation, diameter and dry weight). The analysis of variance

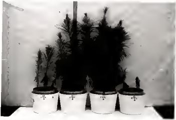


Figure 25.--Seedlings in wet soil to which 600 ppm N were added at varying rates of P. From left to right, 0, 62.5, 125, and 250 ppm P.

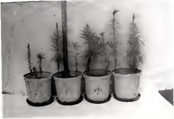


Figure 26.--Seedlings in drained soil that received the same fertilizer treatments as in Figure 25

TABLE 27

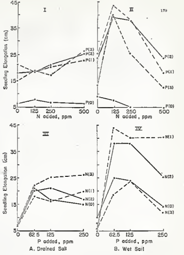
ANALYSES OF VARIANCE FOR EFFECT OF WATER TREATMENTS, N AND P ADDITIONS ON ELONGATION, DIAMETER, DRY WEIGHT OF TOPS AND ROOTS AND ROOT/TOP RATIO OF *P. caribaea* SEEDLINGS

Source	Degree of freedom	Elongation: Mean squares	Elongation: F	Diameter: Mean squares	Diameter: F	Dry weight-tops: Mean squares	Dry weight-tops: F	Dry weight-roots: Mean squares	Dry weight-roots: F	Root/top ratio: Mean squares	Root/top ratio: F
Replications	2	6.89	0.10	0.37	1.04	0.00	-	14.88	2.04	0.11	18.34[1]
Treatments	31										
Water (W)	1	1,003.63	29.23[1]	10.25	28.79[1]	41.59	53.30[1]	30.84	4.33[2]	0.14	2.30
Nitrogen (N)	3	305.35	8.89[1]	11.41	32.06[1]	33.89	43.17[1]	178.95	24.92[1]	0.85	15.26[1]
Phosphorus (P)	3	1,975.41	67.54[1]	26.19	67.31[1]	66.34	85.09[1]	371.30	52.09[1]	0.42	6.80[1]
W x N	3	544.20	15.85[1]	6.44	16.27[1]	18.97	24.31[1]	92.68	13.04[1]	0.33	8.39[1]
W x P	3	190.71	5.55[1]	1.83	5.19[1]	9.40	12.05[1]	27.09	3.80[1]	0.12	2.02
N x P	9	63.58	1.85	1.58	4.44[1]	5.08	6.43[1]	35.08	4.92[1]	0.09	1.50
W x N x P	9	68.63	2.00	1.35	3.79[1]	3.05	3.88[1]	15.18	2.13[2]	0.08	0.95
Error	82	34.33		0.36		0.78		7.13		0.08	

[1] Significant at the 1% level

[2] Significant at the 5% level

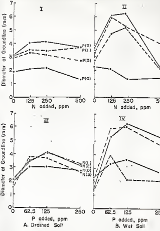
Figure 27.--Effects of water treatments, N and P additions on seedling elongation.



A. Drained Soil

B. Wet Soil

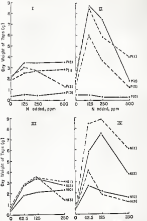
Figure 28.--Effects of water treatments, N and P additions on diameter of seedlings.



A. Drained Soil

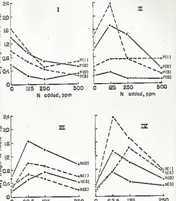
B. Wet Soil

Figure 29.--Effects of water treatments, N and P additions on dry weight of tops.



A. Drained, Soil

B. Wet Soil



A. Drained Soil

B. Wet Soil

Figure 30.—Effects of water treatments, N and P additions on dry weight of roots.

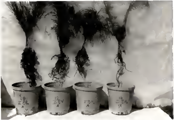


Figure 31 --Root growth of *P. caribaea* seedlings in drained soil that received 250 ppm of P and varying rates of N. From left to right 0, 125, 250, and 500 ppm of N

actual rates. A ratio of about 2 to 1 of N and P appeared to be needed for good seedling growth in this experiment.

Interaction between N and P were detected with stem diameter and dry weight of tops (Figures 28 and 29). In general added N in the absence of added P suppressed growth (Figure 28), while increased N in the presence of added P increased growth of the seedlings (Figure 26).

There was a significant interaction between N and P on dry weight of roots (Table 27). It appeared that in the drained soils, the reducing effect of N on root weight was alleviated in the presence of P. Application of N without P produced seedlings with only 0.26 g roots in drained soil and 0.20 g in wet soils, while seedlings with N and P applications had more roots (Figure 30, I and II).

In the drained soils more roots were formed, when seedlings received P without N (Figure 31), than when P was applied with N. The average values were 1.33 g and 0.85 g, respectively. In contrast, seedlings grown in wet soils with 125 ppm and 250 ppm N, had more roots than seedlings that received no N (Figure 30, IV). The average dry weight of roots at these levels were 1.58 g, 0.98 g and 0.55 g, respectively. All levels of P with 500 ppm of N produced in wet soils, seedlings with a poor root system, averaging 0.45 g.

The average ratios of roots to tops, on a dry weight basis was 0.43:1 for well-drained soils and was 0.38:1 for the soils in which a high water table was maintained. These data are the result of the fact that tops growth was about 60% greater in the high water table soils than in the well-drained soils, while root growth was only 16% greater in the wet soils than in drained soils (Table 37).

The addition of both N and P fertilizers decreased the root/top ratio indicated that P had a much greater effect on tree growth (Table 27). Maximum growth was generally attained at 62.5 and 125 ppm P level (Table 37). At the highest P level of 250 ppm, tree growth was less than at the lower two rates, but it was still higher than that of the zero level. It might be concluded that P was more critical in this soil than N. At any rate seedling growth was much poorer when N was given without P (Figure 32), than when P was applied without N (Figure 33).

The root growth response to P additions reached its maximum at 62.5 ppm of P in drained and wet soils, with average dry weights of 0.9 and 1.2 g respectively (Table 37). Rootweight decreased gradually at higher doses (Figures 30 and 34, III and IV). There were no consistent differences in root growth of seedlings in wet soil and well-drained soil.

Interactions between several of the treatments were highly significant (Table 27). For example, water table x nitrogen interaction was evident by observing that N applied to soils with a high water table treatment tended to produce taller, thicker and heavier seedlings than in well-drained soils, except at the 500 ppm level of N.

Water table x P interaction was also highly significant (Table 27). Seedling response to P tended to be greater in wet soils than in drained soils (Table 37).

A close examination of data for elongation revealed that the maximum response to 125 ppm N occurred in combination with 62.5 ppm P, maximum response to 250 ppm N when combined with 125 ppm P (Table 37), with values of 44 cm and 41 cm,respectively. This suggests that some sort of balance between N and P is necessary for best growth of seedlings, and that within limits the ratio of these two nutrients is more important than the

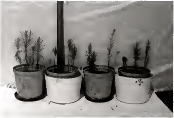


Figure 32.--Seedlings in drained and wet soil with no added P From left to right: No N (drained), No N (wet), 125 ppm N (drained, 125 ppm N (wet)

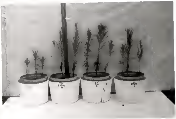


Figure 33.--*P. caribaea* seedlings in wet soils with varying rates of P, but no added N. From left to right: 0, 62.5, 125 and 250 ppm P added.

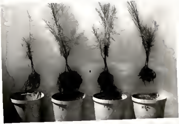


Figure 34 --Root growth in wet soils. Seedlings received no added N, but varying rates of P. From left to right 0, 62.5, 125, and 250 ppm of P

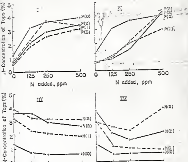
ratios significantly (Table 27). For example, in the drained soils, the ratio was reduced from 0.85 in soils where no N was added to 0.30 where 500 ppm of N were added. Furthermore, where no P was added the ratio was 0.70, but where 250 ppm of P were added the ratio dropped to 0.25. The fertilizers apparently stimulated top growth more than root growth in both wet and drained soils.

Concentration and Total Uptake of Nutrients as Affected by Soil Water Levels and N and P Additions

Tops

Nitrogen in tops.--The N concentrations in the above ground portion of the pine seedlings were influenced by the water table level as well as fertilizer treatments. For example, *P. caribaea* seedlings grown in drained soils generally contained a higher percentage of N than seedlings grown in wet soils. On the average N content in tops of seedlings grown in drained soils was 15% higher than in plants grown in wet soils. However the average N content in tops of seedlings in drained pots was 52 mg, as compared with 55 mg in the wet pots (Table 38), as trees made greater growth in the latter pots.

The application of N fertilizers greatly increased the N concentration in tops, especially when no P was applied. The average N concentration at this level was 3.56% in drained and 3.55% in wet soils (Figure 35, I and II). The concentration of N was significantly reduced (Table 28), as soon as P was applied with N. Application of 125 ppm, 250 ppm and 500 ppm N in combination with 62.5 ppm P, resulted in an average concentration of 3.07% in drained soil and 2.06% in wet soils. This reduction was stronger in the wet than in drained soil, especially at the 125 and 250 ppm rate of N. However increasing P rates decreased N concentration very slightly in drained soil and almost none in the wet soil when combined with 500 ppm N (Table 38).



A. Drained Soil

B. Wet Soil

Figure 35.—Effects of water treatments, N and P additions on N concentration of tops.

TABLE 28

ANALYSES OF VARIANCE FOR EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON N, P AND K CONCENTRATIONS IN TOPS AND N AND P CONCENTRATIONS IN ROOTS OF *P. caribaea* SEEDLINGS

Source	Degrees of freedom	N concentration		P concentration		K concentration		N concentration		P concentration	
		Mean squares	F	Mean squares	F	Mean squares	F	Mean squares	F	Mean squares	F
Replications	2	29.12	1.41	1.24	0.21	0.20	0.20	7.65	0.64	0.61	0.29
Treatments	31										
Water (W)	1	285.58	12.34[1]	17.03	2.86	29.30	29.47	27.27	2.28	48.58	23.15[1]
Nitrogen (N)	3	3,444.91	166.29[1]	103.92	17.73[1]	16.31	16.41[1]	303.56	25.36[1]	15.11	7.69[1]
Phosphorus (P)	3	510.36	28.45[1]	887.63	148.66[1]	29.86	30.03[1]	83.57	6.34[1]	460.21	229.23[1]
W x N	3	231.43	11.71[1]	4.15	0.70	6.43	6.47[1]	17.65	1.48	24.27	11.73[1]
W x P	3	85.73	4.14[1]	15.87	2.88	1.66	1.68	66.30	5.70[1]	38.03	18.16[1]
N x P	9	66.86	3.22[1]	21.22	3.56[1]	4.63	4.65[1]	3.20	0.27	6.61	3.16[1]
W x N x P	9	35.15	1.70	15.23	2.55[2]	1.22	1.22	15.40	1.37	5.23	2.50[2]
Error	62	20.72		5.96		0.99		11.57		2.10	

[1] Significant at the 1% level.

[2] Significant at the 5% level.

The effect of P additions on N concentrations in tops was highly significant (Table 28). The greatest effect of P on reduction of N concentrations was at the 62.5 ppm P level, but at higher applications the effect of added P was different in the wet as in the drained pots (Figure 35, III and IV). It decreased N concentrations in the drained soil at levels higher than 62.5 ppm of P. In contrast it increased N concentrations in wet pots at these levels (Table 38).

The application of P mostly decreased the concentration of N in tops. Trees made increased growth in 62.5 and 125 ppm levels of added P. In these cases the decreased N concentration was likely a dilution effect. However, added P tended to reduce N concentration in drained as well as in wet soils even when no growth response was evident. It appears that added P reduced the availability of N by anion antagonism, or perhaps by increasing the activity of soil microorganisms which in turn used the N in the development of their own population.

Phosphorus in tops.--The average P concentration of the seedling tops was 0.088% in the wet soil and 0.080% when drained (Table 39). Yet the effect of soil water table in this treatment was statistically non-significant (Table 28). Availability of soil P is generally influenced by soil pH. However, the differences in pH between drained and undrained soil were not sufficient to effect detectable differences in availability.

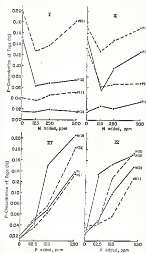
The P concentrations in P. caribaea seedling tops were lower than data reported from similar studies with slash pine (McGee 1983) even when P fertilized. The unfertilized seedlings averaged only about 0.02% P, while those fertilizers with 250 ppm P contained about 0.16% P. The low values were most likely the result of an acid soil rich in Al and Fe which favors the formation of Al and Fe phosphates and makes P largely insoluble and unavailable for trees.

The effect of N on P concentrations of tops was highly significant (Table 28). In the drained soils additions of N up to 125 ppm did not effect this concentration, when P was applied up to 62.5 ppm. At the 125 ppm and 250 ppm P, low rates of N strongly reduced P concentration (Figure 36, II). Concentrations of P increased with applications of N higher than 125 ppm. But seedlings that received 500 ppm of N had lower P concentrations in tops than those that received no N (Figure 38, I and II).

Added P significantly increased P concentrations at all levels in both drained and wet soils (Table 28). Figure 36, III and IV show that the strongest rate of increase of P concentration occurred in seedling tops grown in soils where no N was added. But when the N rates were increased to 125 ppm, the P concentration went down. At the 250 ppm and 500 ppm of N it went up again. All levels of P in combination with the highest level of N resulted in higher P concentrations than in combination with the intermediate levels of N (125 and 250 ppm). This was probably a dilution effect because seedlings had the highest growth rate at the latter levels.

All seedlings, that received no P, had approximately the same P content in tops at all levels of N. It was 0.1 mg in drained as well as in wet soils. In drained soil, increasing rates of N increased P content of seedlings that received 62.5 ppm P, from 0.4 mg when no N was applied to 1.4 mg at 500 ppm of N. In the wet soils the P content at these treatments dropped from 3.5 mg to 1.8 mg (Table 39). In contrast N reduced P content of seedling tops receiving 125 and 250 ppm P grown in drained soil. In the wet soils the effect of N on P content was quadratic with maxima at certain combinations of N and P. These

Figure 36.--Effects of water treatments, N and P additions on P concentration of tops.



A) Drained Soil

B) Wet Soil

maxima were 7.2 mg at 250 ppm N and 125 ppm of P and 7.8 mg at 125 ppm N and 250 ppm P.

Phosphorus increased P content of seedlings, in drained as well as in wet soils. In the wet soils no effect of added P was apparent at rates higher than 125 ppm P (Table 38).

The effect of water treatments was inconsistent with respect to P concentrations and contents.

Potassium in tops.--The average K concentration of seedling tops grown in drained soil was higher than in tops of seedlings grown in wet soils. These values were 0.44% and 0.32% respectively, and were probably related with the growth rate differences in both environments.

Increasing doses of N tended to reduce K concentration in drained soils (Table 40, Figure 37, I), but the effect was inconsistent in wet soils (Figure 37, II).

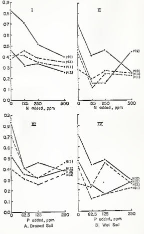
Added P also reduced K concentration of seedling tops. They had a minimum concentration at 125 ppm P in drained soil. This concentration was increased when the rate of application was higher than 125 ppm (Figure 37, III). Its effect in wet soils was inconsistent (Figure 37, IV).

The K concentration in tops of seedlings in unfertilized soil was highest, probably resulting from the small size of seedlings.

The N x P interaction was also significant (Table 28). There was a tendency that added N reduced K concentration more in the presence of P than in the absence of P. Phosphorus also tended to decrease K concentration in drained soil. The reduction was stronger in seedlings that received the high rates of N than the low rates (Figure 37, I and III).

Copper, iron and zinc in tops.--Concentration and total contents of

Figure 37 --Effects of water treatments, N and P additions on K concentration of tops.



A. Drained Soil

B. Wet Soil

Cu, Fe, and Zn in tops of seedlings were affected by water, N, and P treatments. The effects of water table treatments on concentrations and total contents varied among micronutrients. They are summarized below.

	Drained soil		Wet soil	
Micronutrient	Concentration ppm	Content ug	Concentration ppm	Content ug
Copper	8.9	37.2	10.7	48.2
Iron	73.8	168.7	79.1	289.0
Zinc	38.2	81.8	24.8	91.8

Both Cu and Fe concentrations and total contents were on the average higher under wet conditions than in drained soils. Saturation reduced the Zn concentration in tops but increased the total content (Table 41).

If micronutrient concentration of seedlings in unfertilized soils is used as a standard, then increasing rates of N without P, reduced the concentrations and total contents of micronutrients in tissues. This holds true for all three micronutrients, except for the Zn content in drained pots. The greatest reduction in concentration brought about by the high N rates was in a wet environment, and this reduction was often overcome when N was applied together with P.

In contrast, P additions had an opposite effect on micronutrient concentrations to that of N. Copper, iron and zinc concentrations in tops increased with increasing P rates up to 125 or 250 ppm. Total contents of micronutrients were generally greatest at 125 ppm P, and were sometimes as much as twenty times greater than the micronutrient contents of seedling tops grown in unfertilized soil.

Roots

Nitrogen in roots.--The average N concentration of roots in wet soils was 1.38% and 1.28% in drained soils (Table 42), but they were not significantly different according to the analysis of variance (Table 28). Consequently, the total content of N of seedlings in wet pots were also higher because of the larger size.

Applications of N increased N concentration in roots significantly (Table 28, Figure 38, i and ii), but the effect on total N content of roots was erratic for seedlings grown in drained pots. In wet pots, N content of roots was related to development of above ground parts, with average maximum contents at a dose of 125 ppm N, which gradually diminish with increasing rates (Table 42).

Phosphorus significantly increased N concentrations of roots (Table 28) but it increased the total N content of roots when applied up to 125 ppm P only (Table 42).

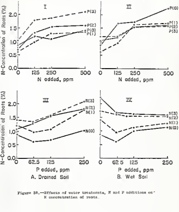
There was also a significant interaction between water and P. It appeared that in the presence of water, the increase of N concentrations by P was very slight (Figure 38, iii and iV).

Phosphorus in roots.--Total content of P in roots averaged 0.76 mg in soils with a high water table but only 0.48 mg in well drained soils (Table 43). This effect of water treatment was highly significant (Table 28).

Increasing N rates strongly suppressed root P concentration in wet soils, except where no P was added. Furthermore, applied N tended to suppress total P content of roots (Table 43).

In general, increasing P rates increased P concentrations in roots significantly (Table 28, Figure 38, iii and IV). Total P content in roots in most cases also increased except in the wet soils where P rates above 125 ppm decreased the P content of roots.

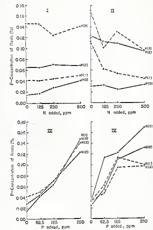
Interaction between water and N was highly significant (Table 28),



A. Drained Soil B. Wet Soil

Figure 38.--Effects of water treatments, N and P additions on N concentration of roots.

Figure 38.--Effects of water treatments, N and P additions on P concentration of roots.



A. Drained, Soil

B Wet Soil

which was illustrated in Figure 29, 1 and 11. In the drained soil added N did not suppress P concentration of roots as in the wet soils.

Interaction between water and P was also highly significant (Table 28)

Total uptake of N and P

The total uptake of N and P were 13% and 62% greater for pine seedlings grown in wet soils than for those grown in drained soils (Table 44). Nutrients are more available in soils with a higher moisture content than in those with a lower moisture content (Metwally and Pollard 1969).

Nitrogen appeared to increase N uptake in drained and wet soils to a certain extent, namely at rates up to 250 ppm, while further additions were either suppressive or improved uptake very slightly.

Phosphorus increased N uptake in drained soils when applied up to 125 ppm and in wet soils up to 62.5 ppm.

Uptake of P was increased by P applications at all levels in both drained and wet soils. In contrast N suppressed total uptake of P at all levels in drained soils. In wet soils however it tended to increase total uptake of P at rates of 125 or 250 ppm N. The highest uptakes of P were found at 250 ppm of N combined with 125 ppm of P and 125 ppm of N with 250 ppm of P, with values of 9.9 mg and 6.6 mg, respectively.

Nitrogen reduced total uptake of P, when applied in combination with low rates of P, in drained as well as in wet soils. It affected P uptake at the highest levels of P also but only in drained soils. The effect in wet soils was quadratic, at these high rates (125 ppm and 250 ppm of P).

Mycorrhizae

Black mantle ectotrophic mycorrhizae with dichotomous branching (Vozzo and Hacskaylo 1964) were more abundant than brown mantle mycorrhizae. White mycorrhizae as described by Griffiths (1965) were not present. His assertion that mycorrhizae on roots of *P. caribaea* did not show apparent structural dichotomy was partially in agreement with observations in this experiment, where dichotomous types were found - often on the same root. In view of the narrow range of conditions favored by each individual species, it would be reasonable to suspect that mycorrhizae species observed by Griffiths (1965) in Malaya were different from those of British Honduras. The latter were adapted to rather unfavorable environmental conditions so prevalent in the savannas of Central America. Plantation in the Jodse Savanna of Surinam failed before nurseries were inoculated with pine ridge soil from British Honduras (Van Suchtelen 1962), very likely because trees growing under similar conditions require a specific fungi.

Inspection with a 15x magnifying binocular revealed that all seedlings grown in soils that received no N had abundant mycorrhizae on their roots at all levels of added P. Only a few seedlings that received the low rate of N had mycorrhizal short roots. There were no mycorrhizal roots present on seedlings that received the 250 and 500 ppm N rates. The optimum N level for mycorrhiza development would appear to be between 0 and 125 ppm, but this may be influenced by the P level in the soil.

High accumulations of N in shoots and roots were associated with high rates of N applications and absence of mycorrhiza. Interestingly when no N was added the total N accumulated in roots is between 41-91% as much as that accumulated in tops, but when N was applied at 125 ppm only 16-26% as much as that accumulated in roots as in tops (Table 28). This was possibly related to mycorrhizal activities. At no N application mycorrhizae were abundant and at 125 ppm of N mycorrhizae were few. This suggested that mycorrhizae took up soil N for metabolic activities

TABLE 28

OCCURRENCE OF MYCORRHIZAE AND ACCUMULATION OF N AND P IN ROOTS AND TOPS OF *P. caribaea* SEEDLINGS

Fertilizers applied		Drained soil				Wet soil			
N	P	Mycorrhiza rating scale[1]	Root	Top	Root/top	Mycorrhiza rating scale[1]	Root	Top	Root/top
---ppm---			------mg------				------mg------		
			Accumulation of N						
0	0	1	5.07	5.59	0.91	1	2.88	7.01	0.41
0	62.5	1	9.75	13.67	0.71	2	8.59	18.03	0.57
0	125	1	9.36	14.37	0.65	2	10.16	13.80	0.75
0	250	1	9.70	14.87	0.65	2	5.64	8.88	0.63
125	0	3	2.84	16.55	0.18	4	4.82	17.25	0.28
125	62.5	3	8.77	52.27	0.16	4	22.43	87.45	0.26
125	125	4	12.15	76.07	0.16	4	19.08	80.70	0.24
125	250	0	11.83	58.86	0.20	0	8.78	55.80	0.16
			Accumulation of P						
0	0	1	0.10	0.07	1.43	1	0.10	0.09	1.11
0	62.5	1	0.68	0.74	0.92	2	1.68	3.60	0.45
0	125	1	0.92	3.21	0.30	2	1.22	3.35	0.36
0	250	1	1.43	4.83	0.29	2	0.84	2.60	0.32
125	0	3	0.04	0.09	0.44	4	0.09	0.16	0.56
125	62.5	3	0.42	1.00	0.42	4	1.40	3.52	0.40
125	125	4	0.60	2.26	0.27	4	1.66	4.97	0.39
125	250	0	0.99	4.21	0.23	0	0.74	7.78	0.09

---

[1] Rating scale

0 = absent
1 = abundant
2 = many
3 = few
4 = scarce

such as for formation of chitin (Koberg 1959) or mycorrhizal sheath (Carradus 1967). The relative amount of total N in roots as compared with shoots dropped abruptly when N was applied and this coincided with absence of mycorrhizae. Phosphorus additions do not interfere with mycorrhiza development, so long as no N was applied simultaneously (Table 28).

In unfertilized drained soil, more P was accumulated in roots than in tops of seedlings. The amounts of P accumulated in roots was 1.43 times as much as in those of the tops. This is also 1.11 times more than the P accumulated in the tops of plants in unfertilized wet soil. This coincided with a high mycorrhiza development, and suggests that mycorrhizae were active in uptake of P which was required to provide energy for their activities.

The mycorrhizae roots accumulated more P with increasing P rates in the drained soil, but in the wet soil P accumulation dropped when P applied was higher than 92.5 ppm.

It appeared that in the case of P. caribaea saturation of the soil with water did not seriously affect the occurrence of mycorrhizae type roots during the period of this experiment. Morphological structures similar to mycorrhizas are sometimes caused by other agents. These results apparently are in conflict with Hacskaylo (1957) who wrote that mycorrhizas need well aerated soil for a good development, and Russell (1961) who stated that waterlogging and reducing conditions in soils inhibit mycorrhizae. It was found in this study that the average weights of mycorrhizal roots in wet soil was 0.90 g and in drained soil 1.15 g.

SUMMARY AND CONCLUSIONS

Growth Conditions of Pine in British Honduras

Growth of *Pinus caribaea* var. *hondurensis*, one of the few pine species known to prosper under a tropical lowland climate in soils of low fertility, was studied in its natural habitat in British Honduras. Four locations in the lowlands and one location in the upland were selected as representing the different soil and climatic conditions of the forested areas of that country. In addition, a greenhouse experiment was conducted with soil collected from a natural pine stand in one of the less productive areas, to study the effect of water table treatments and N and P applications on the growth of pine seedlings.

P. caribaea wood has good qualities for lumber and is also suitable for the production of pulp and paper. Trees may also be tapped for the production of good quality gum and turpentine.

P. caribaea grows on the Atlantic side of Central America, from sea level to about 700 m altitude and between 12° and 18° N latitude. The temperature amplitude ranges between 10 C in the coldest month at the highest elevations and 35 C in the warmest month at sea level. The pines apparently can not survive frost (Nikles 1962, cited by Lamb 1966). It evidently does not grow naturally in areas with an annual rainfall lower than 1,500 mm, as in the northern part of British Honduras, or a greater rainfall level than about 4,000 mm, as in coastal Southern Nicaragua. Although water balance data show a big annual water surplus for the areas, a small deficit at certain periods is probably necessary to induce dormancy. A large deficit during a longer drought period could be fatal because of the low available moisture storage capacity of soils on which the species is generally found.

P. caribaea has been introduced successfully in countries as close to the equator as the Guyanas (Vieira 1967, Versteegh 1968) and as far removed as 28° S latitude in South Africa (Luckhoff 1964), which suggests that this species has very wide day-length tolerance.

This species is adapted to a wide range of physical and chemical soil properties in British Honduras. Soil depth varies from very shallow and waterlogged to very deep and well aerated. Surface soils are generally sandy, but the subsoil varies from sandy and rather loose to clayey and compact. Bulk densities in the root zone ran from 0.50 g/cc to as high as 1.80 g/cc, and values around 1.60 g/cc were very common. This would indicate the adaptability of the species to grow in very compact soil. This fact was also demonstrated by the several clayey horizons whose total porosity was often lower than 40%.

The highest available moisture storage capacity in the top 60 cm of pine ridge soils was 5.7 cm. This was found in the Mountain Pine Ridge, where the soil was high in clay content and contained a large amount of gravel and pebbles. The lowest value overall was 2.6 cm.

The dominating clay minerals were kandites, such as allophanes, kaolinite and halloysite, which indicates that the soils are highly weathered.

All pine ridge soils are acid and the pH range was fairly narrow (between 4.50 and 5.30 for pH in water suspension). The differences between pH in water and KCl suspension, were small, all under 1.0 unit suggesting that exchangeable H are not the primary source of soil acidity.

There was no F layer on the soil surface, but the eluviated horizon was often dark colored, because of the richness in often raw humus. A mixed stand composed of pines and various hardwoods appeared to produce a humus type that is more beneficial to pine growth than a vegetation type consisting mainly of pines and grasses.

The total N in the surface soil varied from medium low (0.05%) to very high (0.28%). Many of the sites in the lowland pine savannas had high values, which may have been contributed by the profuse growth of blue-green algae in the soil. However a great deal of this soil N is possibly organic and not available to trees.

The C/N ratios in the Savanna Pine Ridge soils were all lower than 15, but apparently these low ratios had little effect on the growth of pines, suggesting that these values are not due to good mineralization, but likely to non-symbiotic N fixation by blue-green algae. Only the low C/N ratios in Broken Pine Ridge soils correspond to good growth of pines. Surface soil C/N ratios in the other pine ridges are higher than 20, suggesting that conditions for growth of microorganisms are poor, resulting in a slow rate of mineralization of organic matter.

Several of the pine stands showed good growth in soils where total P was lower than 70 ppm, which indicates that the critical value for total P is possibly lower than 70 ppm. Extractable P in surface soils ranged from 1.5 to 6 ppm, K from 20 to 300 ppm, Mg from 20 to 140 ppm, indicating low requirements of *P. caribaea* for these elements. In contrast extractable Na, which ranged from 80 to 180 ppm was extremely high. It is probable that Na was responsible for the dispersion of colloids in the subsoils, making them compact and impervious.

Extractable Al and Fe contents were extremely high in the surface soil, ranging from 70 to 500 ppm and 3 to 45 ppm, respectively. It is likely that Al is the primary source of the high soil acidity and it may also be responsible for low CEC values. Both Al and Fe may be responsible for P fixation in these acid soils.

Field experiments initiated by the British Honduras Forest Department show that in general pine ridge soils of low fertility respond to small applications of P and the degree of response appears to depend on several factors. These include texture, water table, progeny source, topography, aspect and drainage. Site preparation seems to have no effect after a few years.

Volume growth computed from Experimental and Incremental plots data, ranged between 0.5 m^3/year/ha in the Savanna Pine Ridge to 22 m^3 in the Broken Pine Ridge.

Greenhouse Experiment

In the greenhouse experiment with two levels of water table (drained and wet soil), four levels of N (0, 125, 250, and 500 ppm), and four levels of P (0, 62.5, 125, and 250 ppm), significant growth responses were noted from all three treatments. In pots with continuously wet soil, growth was greatly improved when the soil was fertilized. The pine seedlings show great tolerancy for poor aeration, induced by the high soil moisture, for a period of at least six months.

Optimum response to N and P was generally found on gifts not higher than 125 ppm. Interactions were observed between combinations of water table and N and P treatments.

N seemed to suppress uptake of micronutrients (Cu, Fe and Zn) to near deficiency levels, while P increased their uptake excessively.

Mycorrhizae were apparently affected by applications of N, but not by application of P, and the mycorrhizal fungi could probably resist a high water level and poor aeration.

Optimum Growth Conditions for P. caribaea in a Tropical Lowland

Judged from height, diameter and volume growth in increment plots the climate and natural soil conditions in the Broken Pine Ridge appear to be about optimum for growth of P. caribaea in the lowlands of British Honduras. These conditions can be summarized as follows:

1. The area has an annual rainfall of approximately 2,000 mm with an uneven distribution. It has a drought period of no longer than three consecutive months with a deficit seldom higher than 50 mm. The annual water surplus is approximately 600 mm. A higher surplus may be harmful because of increased nutrient leaching, soil erosion or poor aeration. The temperature is uniform with a mean of around 25 C. The maximum may go as high as 35 C and the minimum as low as 15 C.
2. The species grows well on soils that have good internal and external drainage. Good growth was observed in soils with a loamy texture and with compact clayey horizon deeper than 60 cm.
3. Available water storage capacity in the top 50 cm of soil was as low as 3 to 5 cm.
4. The pH in the surface and subsoil ranged from 4.5 to 5.7.
5. The quality and quantity of humus is very important, as it apparently affects physical and chemical soil properties, such as pH, water-holding capacity, degree of leaching, CEC, and is the principal source of available nutrients in the surface soil. Therefore management practices should be directed towards the production of a mull type of humus, derived from a mixture of hardwood litter and pine needles.

6. Total P was as low as 55 to 116 ppm in the surface soil, and extractable P between 3.8 and 5.7 ppm is apparently sufficient for good tree growth

7 Ammonium acetate-extractable bases varied between 40 and 50 ppm for K, 80 and 180 ppm for Ca, 30 to 50 ppm for Mg and 120-170 ppm for Na.

8. Ammonium acetate extractable Mn ranged between 2.4 and 32.0 ppm and was much lower than the average values found by Hardy et al. (1935) for agricultural soils adjacent to the pine ridges in British Honduras

9 Ammonium acetate extractable Fe and Al was generally not higher than 17 and 250 ppm, respectively. Higher values significantly lower soil pH and availability of P

10. High CEC is evidently not necessary for good tree growth Values of around 5 meq/100 g are adequate, if the soil has a high degree of base saturation.

Feasibility of Introduction of P. caribaea in Kalimantan, Indonesia

Trial plantations of P. caribaea were laid out in Sabah, a territory of Malaysian Kalimantan in 1959. They are located in the Sibuga Forest Reserve, on alluvial soil overlying gravel, with a rainfall as high as 3,150 mm and no annual water deficit The data from this study of conditions in British Honduras, would lead one to conclude that this climate was not optimum, as indicated by Lamb (1966) He suggested the species should be tested in an area with less rainfall Nonetheless, he believed that P. caribaea most likely would grow under Sabah lowland conditions The trees attained a height of 12 m within 5 years. The Honduras variety seemed to be better adaptable to poor soils than the Bahama and Cuban varieties.

The overall characteristic features of the climates of Kalimantan are a heavy rainfall, a uniformly high temperature and high humidity (Table 45). But within the island are areas with a climate approaching 'optimum' British Honduras conditions.

Soils in the Kalimantan lowlands (below 200 m altitude) generally show a close relationship with topography. The following topographic-soil associations proposed by Wall (1964) include (a) Beach, (b) Estuarine, (c) Peat, (d) Riverine, and (e) Dissected Terrace associations. Soils in the first three associations have a low fertility and are frequently waterlogged, at this time they should not be considered for pine plantation.

The Riverine association is nothing but River Alluvial soil (Entisols). Soils of this type, located in hilly areas are mostly well drained because of sandy texture and fertile because of regular replenishment by floods. This area is possibly suitable for *P. caribaea* in view of good growth of this species observed on well drained creek banks in British Honduras.

The Dissected Terrace association are of two types, namely coastal and riverine. The coastal terraces were classified as Humus Podsols (Wood and Beckett 1961), which according to descriptions is possibly Spodosols. It consists mainly of white quartz sand and silt. The humus pan is always found below 1.20 m and internal drainage is good. It supports a type of heath forest, known as kerangas. The soil and the size of trees have much in common with those of the Melinda Coastal Pine Ridge. Although growth conditions are likely not optimum, they should be considered as satisfactory for cultivation of *P. caribaea* for pulpwood.

The riverine terraces are usually less podzolized than coastal terraces and consist mainly of pale colored sandy clays to sandy gravel. They are covered by Lowland Dipterocarp Forests and the soils are classified as Red-Yellow Latosol (Wood and Beckett 1961) or Oxisols. They have somewhat the same morphological, physical and chemical properties as the Broken Pine Ridge sed, therefore, they probably represent the best sites for P. caribaea in the Kalimantan Lowlands.

A paper industry on the island of Kalimantan is planned for the vicinity of Martapura, located in the Ulu Sungai county (Lian 1964). The industry would be based on Agathis borneensis, which grows in scattered stands in the Peat association nearby. The area is swampy and the soil consists mainly of raw peat and muck, resting on impervious clay, and is very poor in chemical constituents. Any species growing under these conditions can not provide a basis for a sound paper industry. The industry needs a sizeable area of trees with an appreciable growth rate. Cultivation of P. caribaea var. hondurensis would probably be an answer to the problem of pulpwood supply for this industry. The soils of the suitable Tope associations in this county are considered by Mohr (1944) to be more productive than the rest of Kalimantan because rivers flowing through the area bring more fertile alluvial silt than in the other regions of Kalimantan. The climate also is somewhat drier than the rest of the island. One fourth of Kalimantan's population is concentrated in this area which comprises less than one-tenth of the island, an indirect illustration of soil productivity.

The climate of the Ulu Sungai county, as represented by Amuntai is very similar to the climate of the Broken Pine Ridge as indicated by potential evaporation, precipitation, actual evaporation, annual water deficit and surplus (Table 15). Therefore one would conclude from this study that climate and soil of selected topographic-soil associations within the Ulu Sungai county are probably suitable for a successful cultivation of *P. caribaea* var. *hondurensis* for a basis of the projected paper industry.

APPENDICES

TABLE 30

ORGANIC MATTER, C, TOTAL N, EXTRACTABLE P, K, Ca, Mg, Mn, Na, Al AND Fe IN UPPER 30 cm SOIL, UNDER *P. caribaea* VAR *hondurensis* IN BRITISH HONDURAS

Profile no	Organic matter	C	Total N[3]	Extractable[1]							
				P	K	Ca	Mg	Mn	Na	Al	Fe
	kg/m²					kg/ha					
				Savanna Pine Ridge							
I	8.33	37,352	2,600	5.4	120	272	193	1.8	417	718	182
II	5.48	26,290	1,803	8.1	118	384	159	2.3	537	456	73
III	8.80	55,042	4,407	7.4	119	88	131	3.0	605	2,305	120
IV	7.39	44,370	3,810	5.3	125	28	141	2.2	432	1,351	43
V	7.41	42,878	3,057	4.8	111	41	64	2.1	450	838	47
VI	4.58	28,364	1,357	10.8	82	128	78	2.8	479	880	54
				Broken Pine Ridge							
VII	7.84	44,892	2,601	8.4	148	380	121	21.70	471	788	53
VIII	7.17	41,582	2,712	18.2	154	688	148	14.7	814	417	23
IX	6.55	37,880	2,363	18.5	240	698	188	8.8	880	405	26
				Melinda Coastal Pine Ridge							
X	5.22	30,218	1,592	8.7	147	368	130	2.0	648	428	40
XI	4.02	23,318	1,310	7.8	133	457	140	2.0	432	532	41
XII	4.81	27,782	1,680	7.4	164	868	548	2.2	500	420	18
				Mountain Pine Ridge							
XIII	6.12	35,428	1,844	2.4	418	448	493	2.8	735	547	25
				Northern Pine Ridge							
XIV	5.11	29,638	881	10.8	388	1,233	809	8.7	448	345	24

---

[1] Extracted by *N* NH_4OAc, pH 4.8.

[2] Walkley-Black Method

[3] Macro-Kjeldahl Method.

TABLE 31

PARTICLE SIZE DISTRIBUTION IN SOILS OF BRITISH HONDURAS
SUPPORTING STANDS OF Pinus caribaea VAR hondurensis

Depth	Horizon	Sand: Very coarse	Sand: Coarse	Sand: Medium	Sand: Fine	Sand: Very fine	Total sand	Silt	Clay	Textural class
-cm-		percent								
		Savanna Pine Ridge								
		Profile I: Puletan loamy sand								
0-15	A_1	5.3	16.2	22.4	25.4	8.8	78.1	14.2	7.7	Loamy sand
15-23	A_2	16.3	18.5	18.2	14.7	3.2	68.9	17.8	12.3	Sandy loam
23+	B_{1t}	5.9	7.4	8.5	9.0	2.6	33.4	17.6	49.0	Clay
		Profile II. Puletan loamy sand								
0-10	A_1	18.0	20.6	20.6	18.4	5.0	83.8	14.8	1.8	Loamy sand
10-18	A_2	42.2	25.2	12.2	6.8	1.5	88.0	8.0	3.0	Sand
18-32	B_{1t}	41.3	17.8	3.5	1.2	0.2	64.1	13.8	22.1	Loamy sand
32-46	B_{21t}	49.5	26.8	5.9	2.7	0.3	85.2	7.4	7.4	Sandy clay loam
46+	B_{22t}	40.8	21.8	4.7	0.8	0.1	68.3	11.8	19.7	Sandy clay loam
		Profile III. Puletan loam								
0-10	A_1	0.8	3.2	8.2	12.7	4.3	30.0	46.6	23.4	Loam
10-18	B_{11}	0.8	2.5	12.1	13.8	5.6	39.0	25.2	35.8	Clay loam
18-25	B_{12}	5.7	14.4	11.1	21.3	8.4	60.9	1.9	37.2	Sandy loam
25-46	B_{21}	4.3	7.8	8.8	12.1	5.2	38.0	24.2	37.8	Clay loam
46-55	B_{22}	9.8	8.1	8.7	8.8	3.7	38.0	23.8	38.2	Clay loam
55-67	B_{3t}	4.7	3.8	4.8	8.1	4.7	27.0	24.0	48.0	Clay

TABLE 31--Continued

Depth	Horizon	Sand: Very coarse	Sand: Coarse	Sand: Medium	Sand: Fine	Sand: Very fine	Sand: Total sand	Silt	Clay	Textural class
--cm--		----------	----------	----------	----------	percent	----------	----------	----------	
					Profile IV: Pulatan loam					
0-8	A_1	1.5	7.5	13.2	20.2	8.8	51.2	30.0	18.8	Loam
8-18	A_{21}	5.4	16.8	13.6	15.0	5.3	56.2	21.8	22.0	Sandy clay loam
18-23	A_{22}	23.3	20.2	7.8	5.5	5.0	61.8	16.8	21.3	Sandy clay loam
23-40	B_{21t}	15.2	14.0	6.4	3.8	3.5	43.0	20.2	36.8	Clay loam
40-50	B_{22t}	5.7	7.8	5.1	7.4	3.6	29.6	20.6	48.8	Clay
50-82	B_{3t}	5.1	6.0	3.6	8.5	2.3	22.5	16.6	57.5	Clay
					Profile V: Pulatan loam					
0-6	A_1	0.6	5.1	15.0	21.5	5.5	47.8	43.5	8.7	Loam
6-15	A_{21}	3.5	15.1	13.7	18.8	8.0	59.1	23.1	17.8	Sandy loam
15-30	A_{22}	18.6	22.5	8.7	11.7	4.0	65.5	17.5	17.0	Sandy loam
30-45	B_{1t}	6.7	8.8	4.5	8.1	2.1	30.2	24.0	45.8	Clay
45-65	B_{2t}	3.5	4.7	3.2	5.4	3.3	20.2	18.4	61.4	Clay
65-90	B_{3t}	4.1	4.2	3.3	5.5	2.3	19.4	18.6	62.0	Clay
					Profile VI: Pulatan loamy sand					
0-10	A_1	20.7	31.8	17.0	7.5	1.4	78.4	16.8	4.8	Loamy sand
10-25	A_2	28.5	34.4	11.1	5.2	1.2	80.4	13.1	6.5	Loamy sand
25-43	B_{1g}	18.6	20.8	11.5	8.4	2.9	61.2	17.6	21.2	Sandy clay loam
43-60	B_{2g}	17.7	18.2	10.2	5.7	2.6	54.4	16.6	29.0	Sandy clay loam

TABLE 31--Continued

Depth	Horizon	Sand: Very coarse	Coarse	Medium	Fine	Very fine	Total sand	Silt	Clay	Textural class
-cm-		------	------	------	------	percent	------	------	------	
Broken Pipe Ridge										
Profile VII. Granodoro sandy clay loam										
0-18	A_1	23.8	21.9	9.8	7.2	2.0	64.4	9.4	26.2	Sandy clay loam
18-23	A_2	3.7	13.3	22.8	20.5	5.9	66.0	18.4	14.9	Sandy loam
23-40	B_1	10.4	16.8	19.3	15.9	3.6	65.0	15.6	19.4	Sandy clay loam
40-65	B_{2t}	8.1	10.1	7.9	6.9	1.9	34.9	16.2	50.0	Clay
65-100	B_{3t}	5.7	7.9	6.6	6.0	2.0	27.8	16.8	55.4	Clay
Profile VIII. Silkgrass sandy loam										
0-15	A_1	0.9	5.8	21.3	27.8	11.3	67.0	27.4	5.6	Sandy loam
15-30	A_2	9.0	25.4	22.9	14.3	5.6	77.2	18.6	4.2	Loamy sand
30-55	B_1	8.7	17.8	20.0	18.9	10.6	75.0	20.2	4.8	Sandy loam
55-80	B_{21}	19.7	29.2	17.0	7.0	0.8	73.8	21.4	4.8	Sandy loam
80-124	B_{22}	23.7	25.6	11.8	8.4	3.3	73.6	9.4	17.0	Sandy loam
124+	B_3	28.8	23.6	10.4	4.2	1.1	68.0	8.6	23.4	Sandy clay loam
Profile IX. Silkgrass sand										
0-13	A_1	0.7	8.2	26.9	38.6	18.5	92.8	1.2	6.0	Sand
13-30	A_2	5.1	18.8	25.3	20.9	8.4	79.0	13.8	7.2	Sandy loam
30-52	B_1	2.6	11.3	21.6	24.2	10.1	69.8	16.8	13.4	Sandy loam
52-87	B_{21t}	13.6	20.4	17.2	13.8	4.2	69.0	10.2	20.8	Sandy clay loam
87-93	B_{22t}	3.9	10.5	10.2	7.4	3.0	35.0	16.4	48.6	Clay

TABLE 21--Continued

Depth	Horizon	Sand: Very coarse	Sand: Coarse	Sand: Medium	Sand: Fine	Sand: Very fine	Sand: Total sand	Silt	Clay	Textural class
-cm-		percent								
		Melinda Coastal Pine Ridge Profile X Sirin loamy sand								
0-13	A_1	8.2	26.4	21.6	16.8	6.0	78.6	14.0	7.4	Loamy sand
13-20	A_{21}	7.4	28.2	24.6	14.8	4.8	80.6	11.2	8.0	Loamy sand
20-45	A_{22}	7.8	28.5	25.3	18.2	4.8	82.4	11.6	6.0	Loamy sand
45-75	B_{1t}	22.8	42.0	8.7	3.8	1.8	78.8	7.0	14.2	Sandy loam
75-88	B_{2t}	17.0	42.8	10.6	4.0	1.0	75.6	8.0	16.4	Sandy loam
		Profile XI Melinda loamy sand								
0-5	A_{11}	4.4	13.5	23.5	28.0	12.4	81.8	15.8	2.4	Loamy sand
5-13	A_{12}	10.3	18.4	21.9	21.1	6.1	78.8	10.8	8.4	Sandy loam
13-25	A_2	8.3	20.5	24.1	20.3	6.8	80.0	12.4	7.6	Loamy sand
25-63	B_1	7.0	16.7	21.1	23.2	11.0	79.0	14.0	7.0	Loamy sand
63-72	B_2	8.9	12.8	18.1	25.1	14.1	78.0	14.2	7.8	Loamy sand
		Profile XII Haciapina loamy sand								
0-15	A_1	3.4	7.6	16.5	33.8	18.3	79.6	14.6	5.8	Loamy sand
15-30	A_2	1.6	6.4	13.2	29.7	17.9	69.0	16.4	14.6	Sandy loam
30+	B_1	2.8	10.5	20.5	31.8	7.2	72.8	19.4	7.8	Sandy loam

TABLE 31—Continued

Depth	Horizon	Sand						Silt	Clay	Textural class
		Very Coarse	Coarse	Medium	Fine	Very fine	Total sand			
-cm-		-percent-								
Mountain Pine Ridge Profile XIII: Pinol sandy clay (hill soil)										
0-8	A_2	28.8	12.4	4.1	1.5	0.1	47.0	17.6	35.4	Sandy clay
8-23	B_{1t}	17.6	10.0	2.8	1.4	0.2	32.0	14.8	53.2	Clay
23-47	B_{2t}	13.5	10.7	3.9	1.8	0.5	30.4	18.8	50.8	Clay
47-92	B_{3t}	25.9	10.8	2.8	1.3	0.4	41.2	20.4	38.4	Clay
92+	C	Not analyzed								
Northern Pine Ridge Profile XIV Tok loamy sand										
0-13	A_1	2.6	10.5	34.3	34.2	4.8	86.4	9.4	4.2	Loamy sand
13-23	A_2	2.3	8.2	29.0	36.6	10.5	86.6	9.0	1.4	Sand
23-30	B_{1t}	2.0	10.0	27.7	28.6	5.1	73.4	8.0	18.6	Sandy loam
30+	B_{2t}	3.4	9.6	22.9	20.1	2.2	58.2	7.6	34.2	Sandy clay loam

TABLE 32

DIFFERENTIAL THERMAL CHARACTERISTICS FOR
KAOLINITE, HALLOYSITE AND ALLOPHANE
(from Holdridge and Vaughan 1957)

Peak	Property of peak	Kaolinite		Halloysite		Allophane	
		Range of temperature	Mean temperature	Range of temperature	Mean temperature	Range of temperature	Mean temperature
		----------	----------	Degrees of centigrade	----------	----------	----------
Endothermic peak A (Figure 40 A)	Start	-	-	50 - 110	81	50 - 100	81
	Maximum	-	-	125 - 150	136	140 - 180	160
	Finish	-	-	190 - 230	203	280 - 350	304
Endothermic peak B (Figure 40 B)	Start	450 - 550	477	380 - 470	411	-	-
	Maximum	570 - 625	607	560 - 590	573	-	
	Finish	640 - 750	689	600 - 640	616		
Exothermic peak D (Figure 40 D)	Start	920 - 980	954	880 - 950	937	830 - 950	904
	Maximum	950 - 1000	980	930 - 980	958	950 - 1000	972
	Finish	980 - 1020	1004	950 - 1010	991	910 - 1050	980

TABLE 33

DISTRIBUTION OF CLAY MINERALS IN THE PINE RIDGE SOILS OF BRITISH HONDURAS, BASED ON IDENTIFICATION WITH DTA

Profile	Horizon	Allophane	Limonite	Gibbsite	Lepidocrocite	Goethite	Siderite	Kaolinite	Halloysite	Montmorillonite
		percent								
I	1	81	6	-	-	-	-	13	-	-
	2	27	23	-	-	-	-	46	-	-
	3	14	-	18	-	1	-	66	-	-
II	1	62	-	-	6	-	6	21	-	-
	2	65	7	-	-	1	2	23	-	-
	3	46	-	20	-	1	-	33	-	-
	4	44	-	20	-	-	2	32	-	-
	5	53	4	-	-	1	1	-	10	-
III	1	55	8	-	-	-	-	-	35	-
	2	36	-	22	-	2	-	-	48	-
	3	28	-	-	22	2	-	48	-	-
	4	46	-	20	-	2	-	-	20	-
	5	30	-	32	-	3	-	-	35	-
	6	11	-	21	-	2	-	56	-	-
IV	1	60	6	-	-	1	1	-	27	3
	2	37	9	-	-	2	-	51	-	-
	3	54	9	-	-	-	-	-	36	-
	4	23	-	18	-	4	-	53	-	
	5	20	-	13	-	6	-	-	60	-
	6	24	4	-	-	6	-	-	65	-

TABLE 33--Continued

Pro-file	Hori-zon	Allo-phane	Limonite	Gibbsite	Lepido-crocite	Goethite	Brucite	Kaolinite	Halloy-site	Montmoril-lonite
		----------	----------	----------	----------	---percent---	----------	----------	----------	----------
V	1	64	-	-	9	3	2	20	-	-
	2	59	7	-	-	2	-	-	30	-
	3	65	7	-	-	1	-	-	25	-
	4	17	-	26	-	2	-	37	-	-
	5	29	-	-	17	5	7	-	39	-
	6	35	6	-	-	5	-	50	-	-
VI	1	41	-	-	9	-	6	19	-	27
	2	54	-	-	-	-	-	-	35	-
	3	27	-	36	-	-	-	-	37	-
	4	23	-	18	-	3	-	55	-	-
VII	1	Not determined								
	2	22	1	-	-	2	-	-	71	-
	3	19	1	-	-	2	-	78	-	-
	4	18	2	-	-	2	-	63	-	4
	5	3	12	-	-	-	-	84	-	-
VIII	1	33	-	-	3	-	7	-	52	-
	2	62	-	-	1	-	1	-	37	-
	3	28	-	23	-	1	2	44	-	-
	4	21	13	-	-	-	-	61	-	-
	5	27	7	-	-	4	-	-	61	-
	6	36	3	-	-	4	-	58	-	-

TABLE 33--Continued

Profile	Horizon	Allophane	Limonite	Gibbsite	Lepidocrocite	Goethite	Brucite	Kaolinite	Halloysite	Montmorillonite
		percent								
IX	1	16	-	-	3	1	1	-	13	65
	2	83	4	-	-	2	-	-	11	-
	3	54	4	-	-	-	-	-	41	-
	4	5	5	-	-	3	-	76	-	6
	6	33	-	-	2	3	-	-	60	-
X	1	73	6	-	-	-	3	16	-	-
	2	75	6	-	-	-	-	16	-	-
	3	87	6	-	-	-	-	7	-	-
	4	43	-	20	-	-	6	-	34	-
	5	54	5	-	-	-	-	-	36	-
XI	1	85	-	-	4	-	-	1	-	-
	2	65	6	-	-	-	-	29	-	-
	3	62	4	-	-	-	-	34	-	-
	4	79	6	-	-	-	-	-	15	-
	5	46	-	17	-	-	-	15	-	-
XII	1	66	-	-	12	-	4	18	-	
	2	47	-	24	-	-	-	20	-	-
	3	Not determined								
XIII	1	-	4	-	-	2	1	-	60	33
XIV	1	-	-	-	-	-	4	46	-	48

TABLE 34

RAINFALL AND TEMPERATURE FOR SOME SELECTED STATIONS IN BRITISH HONDURAS

	Belize Airport			Maskall			Melinda			Savanna			Augustin		
Month	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
January	–	–	111	–	–	113	31.7	14.2	59	30.6	16.6	116	30.5	8.8	73
February	–	–	72	–	–	58	32.5	14.2	71	32.4	18.4	74	32.4	11.8	46
March	–	–	48	–	–	63	33.3	18.6	66	33.9	18.3	80	33.3	13.7	41
April	–	–	76	–	–	56	33.5	16.3	61	33.7	19.3	55	35.6	14.3	55
May	–	–	70	–	–	86	35.8	20.6	140	34.7	18.5	153	34.3	15.0	62
June	–	–	218	–	–	184	34.5	21.5	309	34.0	20.6	293	33.5	18.3	188
July	–	–	256	–	–	247	33.5	21.9	223	32.4	20.2	369	31.6	17.1	152
August	–	–	145	–	–	135	35.0	21.1	200	33.5	20.7	323	32.6	16.1	159
September	–	–	218	–	–	258	34.8	22.2	260	32.3	21.3	340	32.5	16.0	231
October	–	–	239	–	–	268	33.7	16.1	277	31.8	20.2	309	32.7	18.8	248
November	–	–	156	–	–	178	32.2	16.9	237	32.0	17.6	181	29.9	13.6	171
December	–	–	140	–	–	114	33.0	16.7	220	32.7	18.1	137	28.8	8.4	87
Total	–	–	1,746	–	–	1,772	33.5	16.6	2,168	32.8	18.8	2,430	32.3	14.1	1,532

(a) = Average monthly extreme temperature (C) maximum
(b) = Average monthly extreme temperature (C) minimum
(c) = Rainfall (mm).

TABLE 35

AVERAGE CLIMATIC WATER BALANCE DATA FOR SELECTED STATIONS IN BRITISH HONDURAS
(computed by Laboratory of Climatology, Elmer, N. J.)

	J	F	M	A	M	J	J	A	S	O	N	D	T
						Within pine belt area							
						Savanna							
PE	68	86	130	135	156	158	146	146	144	126	88	97	1,520
P	116	74	80	55	153	293	369	323	340	308	161	137	2,430
ST	300	288	244	184	161	300	300	300	300	300	300	300	
AE	68	86	124	115	156	158	146	146	144	126	88	97	1,488
D	0	0	6	24	2	0	0	0	0	0	0	0	32
S	27	0	0	0	0	18	223	175	186	183	62	40	542
						Melinda							
PE	84	84	130	132	168	162	163	162	163	126	110	97	1,571
P	95	71	69	61	140	309	223	210	260	277	237	220	2,156
ST	300	287	234	184	166	300	300	300	300	300	300	300	
AE	84	84	122	111	156	162	163	162	163	126	110	97	1,530
D	0	0	8	21	12	0	0	0	0	0	0	0	41
S	15	0	0	0	0	15	60	38	67	151	127	123	626

PE = Potential evapo-transpiration (mm)
P = Precipitation (mm)
ST = Storage (mm)
AE = Actual evaporation (mm)
D = Deficit (mm)
S = Surplus (mm)

TABLE 35--Continued

	J	F	M	A	M	J	J	A	S	O	N	D	T
Within pine belt area													
Augustin													
PE	85	70	88	120	118	142	118	108	104	99	70	48	1,153
P	73	48	41	55	82	168	152	159	231	248	171	97	1,532
ST	300	277	238	183	188	182	225	276	300	300	300	300	
AE	55	68	80	100	107	142	118	108	104	89	70	48	1,112
D	0	1	8	20	11	0	0	0	0	0	0	0	41
S	18	0	0	0	0	0	0	0	102	150	101	49	420
Maskall													
PE	81	88	114	136	157	164	158	156	142	118	89	85	1,478
P	113	59	88	56	86	184	247	135	256	263	175	114	1,772
ST	300	274	238	178	141	181	270	252	300	300	300	300	
AE	81	88	107	113	124	154	156	153	142	118	88	85	1,409
D	0	1	7	25	33	0	0	3	0	0	0	0	68
S	32	0	0	0	0	0	0	0	68	150	86	25	363
Belize Airport													
PE	81	86	114	138	157	154	158	166	142	118	89	85	1,478
P	111	72	49	76	70	215	256	148	218	239	158	140	1,743
ST	300	286	230	187	139	200	298	287	300	300	300	300	
AE	81	86	106	118	118	154	158	156	142	118	89	85	1,411
D	0	0	8	18	39	0	0	0	0	0	0	0	67
S	30	0	0	0	0	0	0	0	83	121	69	25	338

TABLE 36—Continued

	Month												
	J	F	M	A	M	J	J	A	S	O	N	D	T
Within pine belt area													
Orange Walk (northern borderline of pine belt area)													
PE	81	83	119	138	157	154	158	159	142	118	88	85	1,478
P	83	53	33	34	114	228	181	179	289	134	105	99	1,509
ST	300	288	193	139	121	138	138	219	300	300	300	300	
AE	81	85	103	83	132	154	159	158	142	118	88	85	1,388
D	0	1	11	45	25	0	0	0	0	0	0	0	82
S	9	0	0	0	0	0	0	0	65	16	19	14	113
Outside pine belt area													
Louisville													
PE	81	88	116	138	157	154	159	156	142	118	89	85	1,478
P	84	49	7	30	114	208	144	154	249	148	101	59	1,340
ST	269	239	185	115	99	131	144	143	249	279	291	269	
AE	81	79	79	80	130	154	151	155	142	118	89	83	1,340
D	5	7	35	58	27	0	7	1	0	0	0	2	138
S	0	0	0	0	0	0	0	0	0	0	0	5	5
Corozal Town													
PE	81	86	114	139	157	154	158	159	142	118	89	85	1,479
P	65	35	26	31	105	173	125	197	203	143	134	112	1,318
ST	259	213	180	112	94	113	101	112	173	198	243	270	
AE	79	76	81	79	123	154	137	159	142	118	89	85	1,318
D	2	10	33	59	34	0	21	0	0	0	0	0	159
S	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 35--Continued

	J	F	M	A	M	J	J	A	S	O	N	D	T
Outside pine belt area													
El Cayo													
PE	91	66	114	136	157	164	168	168	142	118	88	83	1,478
P	77	46	41	34	68	135	184	108	212	207	125	131	1,368
ST	286	258	202	143	117	110	136	118	186	275	300	300	
AE	81	83	88	83	124	142	158	120	142	118	89	85	1,342
D	0	3	16	45	33	12	0	27	0	0	0	0	136
S	0	0	0	0	0	0	0	0	0	0	11	46	57

TABLE 36

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON SOIL pH, RESIDUAL TOTAL N, EXTRACTABLE P AND K

Fertilizer treatment		Soil pH		Residual total N		Residual extractable			
						P		K	
N	P	Drained	Wet	Drained	Wet	Drained	Wet	Drained	Wet
ppm		pH		%		ppm			
0	0	5.6	6.2	0.037	0.035	6.0	11.6	20.2	16.4
0	62.5	5.9	6.7	0.031	0.031	15.8	16.3	14.3	12.7
0	125	5.5	6.2	0.040	0.036	25.1	14.3	21.3	14.8
0	250	6.3	6.6	0.028	0.038	33.4	21.4	13.5	9.5
125	0	6.2	5.2	0.044	0.041	6.7	6.7	16.7	17.6
125	62.5	5.7	5.6	0.037	0.038	24.6	14.6	17.0	15.8
125	125	5.8	6.3	0.042	0.032	29.4	10.4	13.4	14.6
125	250	6.0	6.7	0.041	0.041	34.8	32.4	11.4	18.0
250	0	5.7	5.2	0.041	0.041	7.7	6.0	12.7	16.3
250	62.5	5.3	6.8	0.036	0.043	31.0	6.8	18.6	18.2
250	125	6.4	6.4	0.046	0.040	33.2	13.2	12.1	6.0
250	250	6.6	6.4	0.037	0.043	39.6	34.7	16.6	16.0
500	0	6.4	6.2	0.030	0.054	6.5	11.5	11.9	15.8
500	62.5	6.3	5.5	0.053	0.051	23.6	10.9	11.8	14.4
500	125	6.5	5.6	0.046	0.048	36.4	21.2	10.4	13.1
500	250	6.2	6.1	0.034	0.046	43.2	22.6	16.5	22.9
Average		6.6	5.8	0.038	0.041	26.2	16.7	14.8	15.2

TABLE 30--Continued

Fertilizer treatment		Soil pH		Residual total N		Residual extractable			
						P		K	
N	P	Drained	Wet	Drained	Wet	Drained	Wet	Drained	Wet
ppm		pH		%		ppm			
				Average effect					
0	-	5.8	5.9	0.034	0.035	20.5	16.7	17.3	13.4
125	-	5.7	5.6	0.041	0.038	24.4	16.8	14.8	18.8
250	-	5.5	5.6	0.041	0.042	27.8	15.7	15.1	14.4
500	-	5.4	5.8	0.042	0.050	28.3	18.0	12.8	18.8
-	0	5.4	5.2	0.038	0.042	8.8	8.8	15.4	16.6
-	62.5	5.8	5.8	0.040	0.042	23.8	13.7	14.8	14.6
-	125	5.5	6.1	0.048	0.041	31.0	14.8	14.3	12.9
-	250	5.8	6.4	0.035	0.041	37.8	27.8	15.0	17.0

TABLE 37

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON ELONGATION, DIAMETER, DRY WEIGHT OF TOPS AND ROOTS AND ROOT/TOP RATIO OF *P. caribaea* SEEDLINGS

Nutrients added		Elongation		Diameter		Dry weight tops		Dry weight roots		Root/top ratio	
N	P	Drained	Wet	Drained	Wet	Drained	Wet	Drained	Wet	Drained	Wet
---ppm---		---cm/plant---		---mm/plant---		---g/plant---		---g/plant---			
0	0	6.20	9.17	1.67	2.30	0.41	0.53	0.56	0.33	1.49	0.64
0	62.5	21.10	28.10	3.07	3.37	1.82	2.65	1.62	1.39	0.67	0.63
0	125	17.70	24.67	3.06	3.65	2.12	2.17	1.41	0.63	0.66	0.45
0	250	16.27	14.37	2.88	2.73	2.30	1.51	0.96	0.48	0.42	0.32
125	0	7.70	7.93	2.13	2.16	0.81	0.55	0.96	0.38	0.46	0.70
125	62.5	16.36	44.03	3.57	5.96	2.69	8.47	1.01	2.31	0.37	0.27
125	125	17.10	39.73	4.01	6.16	3.54	8.80	0.93	1.70	0.26	0.19
125	250	19.63	40.56	3.26	4.74	3.06	6.02	0.67	0.74	0.22	0.13
250	0	6.87	8.03	2.19	1.36	0.47	0.36	0.18	0.16	0.36	0.45
250	62.5	20.36	36.06	3.49	8.38	2.73	5.63	0.51	0.73	0.18	0.12
250	125	21.20	38.46	4.10	6.24	3.46	7.52	0.74	1.45	0.22	0.19
250	250	17.17	25.13	3.15	5.31	2.70	3.66	0.44	0.73	0.16	0.20
500	0	6.77	5.33	1.47	1.46	0.72	0.26	0.35	0.16	0.47	0.55
500	62.5	22.60	16.96	3.71	3.96	2.80	4.02	0.60	0.73	0.34	0.16
500	125	26.07	24.03	3.71	2.15	3.54	1.63	0.55	0.45	0.18	0.64
500	250	26.23	12.60	2.76	2.06	1.38	1.12	0.28	0.30	0.22	0.55
Average		16.86	23.32	3.04	3.64	2.14	3.48	0.70	0.62	0.43	0.36

TABLE 37--Continued

Nutrients added		Elongation		Diameter		Dry weight tops		Dry weight roots		Root/top ratio	
N	P	Drained	Wet	Drained	Wet	Drained	Wet	Drained	Wet	Drained	Wet
----ppm----		---cm/plant---		---mm/plant---		---g/plant---		---g/plant---			
						Average effect					
0	-	15.07	18.30	2.75	3.01	1.68	1.71	1.18	0.80	0.85	0.49
125	-	15.77	33.08	3.24	4.78	2.48	6.68	0.72	1.28	0.33	0.20
250	-	16.40	28.67	3.23	4.58	2.34	4.35	0.45	0.77	0.23	0.24
500	-	20.18	15.23	2.81	2.41	2.11	1.81	0.46	0.41	0.30	0.48
-	0	6.89	6.87	1.84	1.83	0.53	0.44	0.34	0.26	0.70	0.45
-	62.5	20.81	31.54	3.46	4.87	2.51	5.34	0.66	1.29	0.44	0.28
-	125	20.26	31.70	3.73	4.55	3.17	5.03	0.81	1.15	0.33	0.37
-	250	19.65	23.17	3.02	3.72	2.36	3.08	0.58	0.87	0.25	0.30

TABLE 38

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON N CONCENTRATIONS AND CONTENTS IN TOPS OF P. caribaea SEEDLINGS

	Phosphorus added (ppm)									
	0		62.5		125		250		Average	
Nitrogen added ppm	Concentration %	Content mg	Concentration %	Content mg	Concentration %	Content mg	Concentration %	Content mg	Concentration %	Content mg
					Drained soil					
0	1.36	6.6	0.74	13.7	0.66	14.4	0.65	14.9	0.88	12.1
125	3.23	16.6	2.31	62.1	2.14	74.8	1.63	69.0	2.40	63.4
250	3.47	16.4	3.56	66.1	2.88	100.0	2.56	68.0	3.16	71.0
500	3.44	16.7	3.33	63.2	3.32	117.6	3.11	43.0	3.41	70.4
Average	3.01	16.7	2.50	66.8	2.26	77.0	2.06	46.4	2.46	61.7
					Wet soil					
0	1.32	7.0	0.67	15.1	0.63	13.6	0.59	8.8	0.78	11.2
125	3.14	17.3	1.03	47.2	0.82	61.0	0.80	54.2	1.60	62.9
250	3.77	14.3	2.09	121.6	1.60	120.4	2.16	76.6	2.40	83.8
500	4.08	11.6	3.05	122.5	4.21	77.2	4.04	45.1	3.85	64.1
Average	3.08	12.5	1.66	86.7	1.84	73.1	1.82	46.7	2.13	64.7

TABLE 39

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON P CONCENTRATIONS AND CONTENTS IN TOPS OF *P. caribaea* SEEDLINGS

	Phosphorus added (ppm)									
	0		62.5		125		250		Average	
Nitrogen added	Concentration %	Content mg	Concentration %	Content mg	Concentration %	Content mg	Concentration %	Content mg	Concentration %	Content mg
					Drained soil					
0	0.02	0.1	0.04	0.8	0.15	3.2	0.22	4.9	0.11	2.2
125	0.02	0.1	0.04	1.0	0.06	2.3	0.14	4.2	0.06	1.9
250	0.02	0.1	0.05	1.3	0.07	2.4	0.14	3.8	0.07	1.9
500	0.01	0.1	0.05	1.4	0.09	2.7	0.18	2.5	0.09	1.7
Average	0.02	0.1	0.04	1.1	0.09	2.6	0.17	3.9	0.08	1.9
					Wet soil					
0	0.02	0.1	0.13	3.5	0.15	3.4	0.17	2.6	0.12	2.4
125	0.03	0.2	0.04	3.5	0.06	4.9	0.13	7.5	0.09	4.1
250	0.02	0.1	0.05	2.7	0.10	7.2	0.15	5.5	0.09	3.9
500	0.04	0.1	0.04	1.8	0.13	2.4	0.17	1.9	0.09	1.9
Average	0.03	0.1	0.07	2.6	0.11	4.5	0.16	4.4	0.09	3.0

TABLE 40

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON K CONCENTRATIONS AND CONTENTS IN TOPS OF *P. caribaea* SEEDLINGS

Nitrogen added ppm	Phosphorus added (ppm) 0 Concentration %	0 Content mg	62.5 Concentration %	62.5 Content mg	125 Concentration %	125 Content mg	250 Concentration %	250 Content mg	Average Concentration %	Average Content mg
					Drained soil					
0	0.83	3.4	0.41	7.5	0.47	10.0	0.38	8.7	0.52	7.4
125	0.72	3.7	0.42	11.3	0.32	11.3	0.46	14.1	0.46	10.1
250	0.53	2.5	0.36	8.5	0.34	11.8	0.40	10.6	0.41	8.7
500	0.41	2.6	0.31	8.7	0.26	8.2	0.35	4.8	0.33	6.4
Average	0.62	3.1	0.38	9.3	0.35	10.6	0.40	9.6	0.44	8.2
					Wet soil					
0	0.71	3.8	0.44	11.5	0.48	10.4	0.29	4.4	0.48	7.6
125	0.43	2.4	0.11	9.3	0.16	14.1	0.21	12.8	0.23	6.8
250	0.46	1.6	0.26	14.6	0.16	12.0	0.28	10.2	0.29	9.7
500	0.27	0.6	0.24	9.6	0.46	8.4	0.25	2.8	0.30	5.4
Average	0.47	2.2	0.26	11.3	0.32	11.2	0.26	7.8	0.32	6.0

TABLE 41

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON Cu, Fe AND Zn CONCENTRATIONS AND CONTENTS IN TOPS OF *P. caribaea* SEEDLINGS

	Phosphorus added (ppm)									
	0		62.5		125		250		Average	
Nitrogen added ppm	Concentration ppm	Content ug	Concentration ppm	Content ug	Concentration ppm	Content ug	Concentration ppm	Content ug	Concentration ppm	Content ug
					Cu in Tops					
					Drained soil					
0	8.2	2.3	8.8	10.0	8.3	19.8	13.7	20.8	8.7	13.9
125	5.7	3.1	8.2	83.2	18.5	182.8	14.8	69.3	11.8	81.1
250	2.8	1.1	10.0	58.3	7.2	53.9	10.8	38.8	7.7	38.9
500	3.2	2.3	8.3	17.7	8.2	28.9	11.3	18.7	7.2	18.2
Average	4.8	2.2	7.8	30.8	10.8	66.4	12.7	41.3	8.8	37.3
					Wet soil					
0	8.2	3.8	25.9	67.5	18.8	36.5	8.3	14.1	14.8	30.4
125	4.3	2.4	13.2	128.4	13.7	120.3	20.8	123.4	13.4	93.9
250	2.2	0.8	11.0	64.1	17.8	134.1	12.8	46.9	10.2	81.9
500	1.2	0.3	5.2	20.9	3.3	8.1	5.3	1.9	3.7	7.2
Average	3.9	1.8	14.2	70.2	12.9	74.2	12.0	48.5	10.7	48.2

TABLE 41--Continued

Nitrogen added ppm	Phosphorus added (ppm)									
	0		62.5		125		250		Average	
	Concentration ppm	Content ug	Concentration ppm	Content ug	Concentration ppm	Content ug	Concentration ppm	Content ug	Concentration ppm	Content ug
					Fe in Tops					
					Drained soil					
0	75.0	30.8	73.3	133.7	43.5	60.2	76.7	175.8	68.6	107.6
125	64.2	32.3	88.3	237.6	155.8	552.1	75.8	231.7	66.0	263.4
250	51.7	24.4	53.3	255.1	47.5	233.6	80.8	137.4	65.8	162.8
500	62.5	44.8	101.7	234.7	46.7	165.4	80.0	66.3	65.2	141.0
Average	63.3	33.2	69.2	227.7	78.1	250.3	63.3	153.5	73.5	166.7
					Wet soil					
0	94.2	49.9	187.5	415.9	52.5	113.6	67.5	147.2	100.4	181.9
125	56.2	32.5	110.6	538.3	75.0	660.0	78.3	471.5	80.8	525.6
250	53.3	20.1	66.7	553.6	61.7	463.6	63.3	231.5	68.8	319.8
500	45.8	13.0	45.6	184.0	45.8	184.0	123.3	134.4	68.5	126.6
Average	63.1	28.6	102.7	525.7	56.8	355.4	91.8	246.2	76.1	268.0

TABLE 41--Continued

Nitrogen added	Phosphorus added (ppm)									
	6		88.5		125		250		Average	
	Concentration	Content	Concentration	Content	Concentration	Content	Concentration	Content	Concentration	Content
ppm	ppm	ug	ppm	ug	ppm	ug	ppm	ug	ppm	ug
					Zn in Tops					
					Drained soil					
0	38.3	14.6	18.8	30.7	33.7	71.5	28.0	66.4	29.0	45.6
125	26.5	13.8	27.8	74.6	24.0	85.0	42.5	129.6	30.2	75.8
250	17.3	8.2	33.0	90.2	40.5	140.1	46.8	126.8	34.4	91.3
500	32.8	23.3	37.0	103.8	45.7	161.6	122.0	168.7	56.3	114.3
Average	28.2	15.0	28.7	74.8	36.0	114.6	60.1	122.8	35.2	81.8
					Wet soil					
0	32.2	17.0	89.2	156.6	27.2	68.8	17.3	28.2	34.0	64.7
125	17.8	9.8	23.8	160.0	23.6	206.7	29.5	177.6	23.7	146.0
250	7.7	2.9	31.8	127.3	29.2	218.4	38.2	136.5	24.2	122.3
500	3.8	1.1	16.3	81.6	16.8	30.8	28.5	33.0	16.4	31.6
Average	15.4	7.7	20.3	138.1	24.2	130.7	28.6	94.1	24.6	91.2

TABLE 42

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON N CONCENTRATIONS AND CONTENTS IN ROOTS OF *P. caribaea* SEEDLINGS

Nitrogen added	Phosphorus added (ppm)									
	0		62.5		125		250		Average	
	Concentration	Content	Concentration	Content	Concentration	Content	Concentration	Content	Concentration	Content
ppm	%	mg	%	mg	%	mg	%	mg	%	mg
					Drained soil					
0	0.88	5.1	0.80	8.7	0.81	8.6	1.01	6.8	0.77	8.3
125	1.21	3.0	0.87	8.8	1.30	12.1	1.78	11.6	1.31	8.2
250	1.07	1.8	1.28	6.5	1.53	11.3	1.86	8.3	1.44	7.0
500	1.38	4.8	1.31	8.0	1.58	8.5	2.10	5.8	1.59	7.0
Average	1.13	3.7	1.04	8.8	1.25	10.1	1.68	8.9	1.28	7.8
					Wet soil					
0	0.87	2.9	0.82	8.8	1.03	10.2	1.15	5.7	0.82	6.8
125	1.70	6.6	0.97	22.4	1.13	16.1	1.18	8.8	1.24	14.2
250	1.74	2.7	1.64	12.0	1.55	22.4	1.52	11.1	1.61	12.1
500	2.22	3.4	1.67	12.3	1.61	7.2	1.57	4.8	1.77	6.8
Average	1.63	3.8	1.23	13.8	1.33	14.7	1.36	7.6	1.38	10.0

TABLE 43

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON P CONCENTRATIONS
AND CONTENTS IN ROOTS OF *P. caribaea* SEEDLINGS

Nitrogen added	Phosphorus added (ppm)									
	0		62.5		125		250		Average	
	Concentration	Content	Concentration	Content	Concentration	Content	Concentration	Content	Concentration	Content
ppm	%	mg	%	mg	%	mg	%	mg	%	mg
					Drained soil					
0	0.02	0.1	0.04	0.7	0.07	0.9	0.13	1.4	0.07	0.8
125	0.02	0.0	0.04	0.4	0.07	0.6	0.15	1.0	0.07	0.5
250	0.03	0.1	0.05	0.2	0.07	0.5	0.12	0.8	0.07	0.4
500	0.04	0.2	0.05	0.4	0.07	0.4	0.14	0.4	0.08	0.3
Average	0.03	0.1	0.05	0.4	0.07	0.6	0.14	0.8	0.07	0.5
					Wet soil					
0	0.03	0.1	0.11	1.6	0.12	1.2	0.17	0.8	0.11	0.9
125	0.03	0.1	0.06	1.4	0.12	2.0	0.10	0.6	0.08	1.1
250	0.03	0.0	0.06	0.4	0.11	1.6	0.13	1.0	0.08	0.8
500	0.03	0.1	0.08	0.3	0.10	0.4	0.10	0.3	0.07	0.3
Average	0.03	0.1	0.07	0.9	0.11	1.3	0.13	0.7	0.8	0.8

TABLE 44

EFFECT OF WATER TREATMENTS AND N AND P ADDITIONS ON TOTAL UPTAKE OF N AND P BY *P. caribaea* SEEDLINGS

Nitrogen added ppm	Phosphorus added (ppm) 0 Drained	0 Wet	62.5 Drained	62.5 Wet	125 Drained	125 Wet	250 Drained	250 Wet	Average Drained	Average Wet
	mg/plant									
				Total uptake of N						
0	10.6	8.5	23.4	23.7	23.0	23.8	24.6	14.8	20.4	18.0
125	18.5	23.8	71.9	109.8	88.0	100.1	70.6	63.0	82.6	74.1
250	16.8	16.8	104.8	133.6	111.3	142.8	77.2	88.7	78.0	86.0
500	32.6	18.0	102.2	134.7	128.2	84.4	48.6	93.7	77.4	62.0
Average	20.4	16.4	75.5	100.4	87.1	87.8	55.4	85.2	60.0	87.8
				Total uptake of P						
0	0.2	0.3	1.4	5.1	4.1	4.8	6.4	6.8	3.0	3.8
125	0.1	0.3	1.4	4.6	2.6	8.8	5.2	8.5	8.4	5.1
250	0.1	0.1	1.8	3.1	2.8	4.8	4.3	6.4	2.2	4.8
500	0.2	0.2	1.6	2.2	3.0	2.8	3.2	2.2	2.0	1.8
Average	[illegible]	[illegible]	1.8	[illegible]	[illegible]	5.3	4.7	[illegible]	[illegible]	[illegible]

TABLE 45

CLIMATOLOGICAL DATA OF SOME SELECTED STATIONS IN THE ISLAND OF KALIMANTAN

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
						Water balance Amuntai (mm)[1]							
PE[4]	124	115	125	122	130	122	126	132	130	132	122	126	1,508
P	292	281	308	232	191	124	89	18	73	113	329	298	2,275
ST	300	300	300	300	300	300	285	212	175	188	273	300	
AE	124	116	128	122	130	122	124	119	111	123	122	126	1,465
D	0	0	0	0	0	0	2	13	19	9	0	0	43
S	188	145	179	110	81	2	0	0	0	0	0	145	810
						Temperature Kuching (C)[2]							
Maximum	29.4	29.7	30.8	31.5	32.1	31.9	32.0	31.4	31.2	31.1	31.0	30.0	31.0
Minimum	22.3	22.3	22.2	22.3	22.8	22.8	22.1	22.1	22.2	22.3	22.1	22.4	22.3
						Relative humidity Kuching (%)[3]							
RH at 2 P M	78.5	76.1	71.7	65.9	63.5	64.3	57.9	57.9	73.8	69.5	70.2	79.9	70.8

[1] From Laboratory of Climatology 1963 Average climatic water balance data of the continents Part II. (Asia (Excluding U.S.S.R.) Publ. of Climatology XVI(1) 131.

[2] Compiled from Annual Reports of the Government of Sarawak Her Majesty's Stationery Office London England The figures are averages from 1954, 1955, 1957, 1958, 1959, 1961 and 1962.

[3] For 1952 only.

[4] Refer to Table 35 for meaning of abbreviations

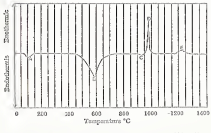


Figure 40 —General differential thermal curve for kandites using a 10C/min heating rate: A-removal of adsorbed water, B-removal of combined water, C-removal of last traces of water or structural rearrangement, D-formation of mullite and/or γ-Al_2O_3, E-formation of cristobalite or rapid formation of mullite (after Holdridge and Vaughan 1957).

APPENDIX 1

Plant Formations in British Honduras in which *Pinus caribaea* var. *hondurensis* is an Associated Species*

(from Romney 1959)

SHRUBLAND WITH PINE

The three assemblages in this transition group are all, to some extent, invaded by pines. They are known locally as 'broken pine ridge'. Individual pines may rise to 18 m, i.e. some 12 to 13.5 m above the level of the main plant cover.

18 PINE--Melastoma forest with craboo, cutting grass and palmetto abundant palms. It occurs on muscovite granite soils near Stann Creek. The soil has been leached considerably resulting in a loose sandy topsoil and a very compact mottled subsoil. The relief is flat to gently sloping.

18a OAK--Pine forest with yemeri, craboo, black and white waya, chunuk, polewood, florneul, Dicranopteris fern and cutting grass. It occurs on quartzite hills and terraces in the 2,250-3,750 mm rainfall zone, and on some shale hills under slightly higher rainfall. Occasionally it is found at over 650 m. The soils have grey sandy topsoils and dull greyish-yellow, mottled orange and red, compact subsoils.

18b PINE--Oak forest with craboo, oak, black and white waya, cylady and cutting grass. This type occurs on old high river terraces in the middle reaches of the Belize and Sibun Rivers. The soils have settled stony clay subsoils and light grey leached sandy topsoils.

---

*Numbers as used in original source

PINE FOREST AND ORCHARD SAVANNA

Orchard savanna with occasional lime-loving species

This is a very open type of broken pine ridge found on but a small part of the Northern plain.

17 OAK--Damsel woodland, with pine, burbs jolute and grass. This assemblage is peculiar to flinty soils in limestone areas from which the lime has been largely leached, and to one or two areas of pale brown clay. On the latter soil the type of vegetation present may be due as much to extreme of moisture variability as low fertility.

Orchard savanna (without lime-loving species) and true savanna

This is quite a widespread type of plant cover in British Honduras. It occurs in two main localities--the uplands of the 'Mountain Pine Ridge' and the lowlands of the coastal plain. Much of the savanna and orchard savanna of the 'mountain pine ridge' may be a fire-induced formation. The natural vegetation may well have been a light forest with oak, Clusia, Laurathea, as well as Tapirira and other species now rarely met. The main species of oak present are Quercus alivifolia, Q. hondurensis and Q. sapitefolia but there seem to be at least six species and numerous hybrids.

18 OAK--Pine-Flerogul forest. This also includes species like chumuk, Clusia sp., crabboo and sandpaper tree. Silver pimento palms frequently occur in clumps. The whole assemblage may be open, or may be grouped in clumps with open grass between. Nargusta is occasionally found, but mahogany never. When protected from fire the

grasses grow long and many small shrubs appear. Dumb cane is an early colonist. Soils are pinkish-brown, not markedly mottled and developed on rolling to hilly land. A few trees of *Podocarpus guatemalensis* Standl. occur in this assemblage.

18a OAK--*Pine*-Clusia *spp. forest*, with abundant silver pimento. This resembles the last assemblage except that it is usually more open and does not readily revert to tall grass and shrubland. It is found occupying much of the 'Mountain Pine Ridge'. The *Clusia* species is generally *Clusia Massoniana*. It is commonest on rolling to hilly slopes. The soils are variable, but in general show a grey topsoil overlying a pale reddish-brown, slightly mottled, sandy clay subsoil.

18b SAVANNA *grass* with scattered pine, oak, *Leucothoe* sp., *Clusia* sp. and crabboo. This assemblage covers almost all the flattish and undulating part of the 'Mountain Pine Ridge'. The soils are pale brownish-grey loamy coarse sands, often 45-50 cm deep, over a hard mottled clay. Pine will regenerate on this soil when given fire protection.

Where remnants of the limestone sheet is still extant, the botan palm, with *Cordia polycephala*, *Phoebe longicaudata*, Florasul and mahogany (less than one to 10 acres) are present. The main grasses on the 'Mountain Pine Ridge' savanna are *Andropogon* spp., *Eragrostis maypurensis*, *E. spectabilis*, *Panicum laxum* and *P. fusiforme*, *Paspalum paniculatum*, *Setaria tenax*, *S. geniculata*, *Sporobolus indicus* and *Trachypogon angustifolius*. Sedges are mainly *Cyperus* spp. and *Scleria ciliata*.

The lowland 'pine ridge' includes a wide range of related soils, most of the soil variation being easily picked out by vegetation differences, despite regular and frequent burning. The composition of the pasture shows rather more variation on the different soils than the forest components. The pattern is conspicuous but very intricate and only the broadest generalization has been attempted on the vegetation map

19 GRASS with scattered pines and pine clumps Crabboo, yaha and oak are occasional trees in the landscape. The soils are sands resting on sandy clay or gravelly sandy clay The land is usually very gently sloping.

19a SEDGES, grasses and a few isolated islands of pine, oak, crabboo, yaha, *Leucothoe* sp., etc. Each island of forest is often surrounded by a fringe of salt-water pimento palms Calabash trees 25-35 m high are commonly dotted about on the plains. The soils have 7-30 cm of fine, sandy, slightly silty, colluvium over a grey mottled sandy clay subsoil. The land is almost flat

19b PALMETTO *palm clumps* with grass and sedges in between. This landscape has no pines, and oaks and crabboo occur only as small island clumps marking out the better-drained patches. Calabash are few and scattered. The soils are dark, often slightly peaty, loamy sands over white sand or pale grey mottled sandy clays. A fine hog-wallow micro-relief usually obtains.

APPENDIX 11

Morphological Properties of Pine Ridge Soils

Profile 1: Puleton loamy sand

Location: Savanna Forest Division, Mango Creek Forest Reserve.

Description: The vegetation is composed primarily of sedges and grasses, a very limited number of bushy species as oak, crabboo, yaha, *Leucothea* sp. *P. caribaea* grows sporadically in small groups that are very widely scattered. The soil is derived from coastal deposits. The topography is flat and occasionally concave at an elevation of not higher than 5 m. The soil is subject to some sheet erosion due to frequent flooding, although movement of water over the surface is slow. Internal drainage is very slow and the water table in the rainy season does not go lower than 25 cm. The area could be classified as "very poorly drained".

New Classification: Order .... Ultisols

Suborder .... Aquults

Horizons:

A_1 -- 0-15 cm -- Very dark grey (7.5 YR N 3/) loamy sand, high in organic matter (raw humus) and is strongly acid. The structure is very fine crumb, with moderate aggregation. The consistence is nonsticky when wet, and loose when moist or dry.

A_2 -- 15-23 cm -- Brownish-yellow (10 YR 6/6) sandy loam, that is very strongly acid and is much less in organic matter than the surface horizon. It has a fine crumb structure with moderate grade, is sticky when wet, very friable when moist and slightly hard when dry.

B_1 -- 23+ cm -- Yellow (10 YR 8/6) clay, with abundant reddish concretions. The soil is more or less structureless (massive), very sticky and plastic when wet, extremely firm when moist and very hard when dry.
Deeper sampling is impossible because of the groundwater.

Profile 11. Puletan loamy sand.

Location. Savanna Forest Division, Mango Creek Forest Reserve.

Description. The vegetation is composed of savanna grass with scattered pines, oak, Leucothe sp., Clusia sp. The parent material is coastal deposit. The relief is flat, located at low elevations (7 m). In rainy seasons, it is frequently flooded, resulting in some sheet erosion. The internal and external drainage is very slow. The water table is at 45 cm, a little deeper than on Profile 1, presumably because of the difference in elevation of the microsite. The soil could be classified as 'poorly drained".

New Classification. Order .. ... Ultisols

Suborder .... Udults

Horizons.

A_1 -- 0-10 cm -- Black (7.5 YR N 2/), humus loamy sand, with apparently no structure (single grain) and is very strongly acid. The consistence is nonsticky nonplastic when wet, and loose when moist.

A_2 -- 10-18 cm -- Reddish-grey (10 R 5/1), strongly acid sand, with a medium crumb, strong structure and with a consistence that is nonsticky, nonplastic when wet, very friable when moist and soft when dry

B_1 -- 18-32 cm -- Brownish-yellow (10 YR 6/8), loamy sand that is strongly acid. The structure is medium, coarse angular blocky and of moderate grade. The consistence is sticky and plastic when wet, firm when moist, hard when dry and is weakly cemented with yellowish mottling.

B_{21t} -- 32-45 cm -- Light yellowish-brown (2.5 Y 6/4), strongly acid sandy clay loam. The structure is medium to coarse, angular blocky and weak. The consistence is sticky and slightly plastic when wet, firm when moist and hard when dry, with strong cementation and some mottling.

B_{22t} -- 45+ cm -- Red (10 R 4/8), sandy loam that is strongly acid. The structure is very coarse subangular blocky and tends to be massive. The consistence is slightly sticky and nonplastic when wet, extremely firm when moist, and very hard when dry. It grades then to an indurated soil.

Profile III. Puletas loam.

Location: Savanna Forest Division, Mango Creek Forest Reserve.

Description: The vegetation is dense P. caribaea in natural stands, with trees higher than 10 m. A dense undergrowth of bush species and sparse grass is present. Parent material is coastal deposit. Relief is normal at an elevation of 6 m, flat to weakly sloping. Soil is moderately deep, no signs of erosion are observed. Internal and external drainage is medium fast, because of moderate permeability and weak slope.

New Classification: Order [illegible]. Ultisols

Suborder [illegible] Udults

Horizons:

A_1 -- 0-10 cm -- Very dark gray (7.5 YR N 3/), humus (raw humus) loam with a very strong acidity, fine, crumb, strong structure. It is nonsticky and nonplastic when wet, very friable when moist and has a soft consistence when dry.

B_{11} -- 10-16 cm -- Dark reddish-brown (5 YR 2.5/2), clay loam. Except for texture, it has similar structure and consistence as previous horizon.

B_{12} -- 16-25 cm -- Light yellowish-brown (2.5 Y 6/4), sandy clay. It has the appearance of a strongly leached horizon. Soil is very strongly acid, with a blocky, fine to medium and moderate grade structure. The consistence is slightly sticky and plastic when wet, friable when moist and slightly hard when dry. It seems to be weakly cemented.

B_{21} -- 25-45 cm -- Yellowish-brown (10 YR 5/6), clay loam and is very strongly acid. Abundant ferruginous mottling is visible. The structure is medium to coarse, subangular blocky in a moderate grade. The consistence is sticky and slightly plastic when wet, firm when moist, and hard when dry. Peds are weakly cemented.

B_{22} -- 45-55 cm -- Very pale brown (10 YR 7/4) and very strongly acid clay loam. The structure is fine to coarse, angular blocky with moderate aggregation. The consistence is very sticky and plastic when wet, extremely firm when moist and hard when dry and strongly cemented.

B_{3t} -- 55-75 cm -- Pale brown (10 YR 6/3), strongly cemented massive clay.

Profile IV: Puletze loam

Location: Savanna Forest Division, Mango Creek Forest Reserve.

Description: Soil under a successful P. caribaea plantation, with dense undergrowth of bush and grass underneath. Parent material is coastal deposit and colluvium. Terrain has a normal relief, at an elevation of approximately 8 m, is flat or nearly flat topography. The soil is deep. External drainage is good, but internal drainage is somewhat stagnant.

New Classification: Order ..... Ultisols

Suborder ...... Udults

Horizons:

A_1 -- 0-8 cm -- Black (2.5 YR N 2/), very rich in humus and very strongly acid loam. The structure is fine to medium crumb with moderate aggregation. The consistence is non-sticky, nonplastic when wet, very friable when moist and soft when dry.

A_{21} -- 8-18 cm -- Dark gray (7.5 YR N 4/), high in organic matter, very strongly acid, sandy clay loam. The structure is fine to medium crumb with moderate aggregation and the consistence is sticky and slightly plastic when wet, very friable when moist and soft when dry.

A_{22} -- 18-23 cm -- Light yellowish-brown (10 YR 6/4), sandy clay loam, extremely acid eluviated horizon, with fine to medium blocky, weak structure and sticky, slightly plastic when wet, very friable when moist, and slightly hard when dry.

B_{21t} -- 23-40 cm -- Brownish-yellow (10 YR 6/6), clay loam, with red ferruginous mottling. The soil is very strongly acid, with medium subangular blocky structure, weakly aggregated. Soil is sticky and plastic when wet, firm when moist, and slightly hard when dry. Peds appear to be weakly cemented. The soil is mottled from this horizon down.

B_{22t} -- 40-60 cm -- Reddish-yellow (7.5 YR 6/6), very strongly acid clay, with a medium, subangular blocky weak structure with a sticky and plastic consistence when wet, very firm when moist, and hard when dry.

B_{3t} -- 60-82 cm -- Reddish-yellow (5 YR 6/8), clay, which is extremely acid, massive structure, very sticky and plastic in a wet condition, yet extremely firm when moist and extremely hard when dry.

Profile V: Puleton loam.

Location: Savanna Forest Division, Mango Creek Forest Reserve.

Description. Soil in P. *caribaea* plantation planted in 1952, 6 m tall trees making poor growth. There are many openings in the stand and the area is covered with grasses, but bushy species are sparse. Site has a normal to flat relief at 10 m elevation and drainage is also moderate.

New Classification: Order [illegible], Ultisols

Suborder [illegible], Udults

Horizons.

A_1 -- 0-8 cm -- Very dark grey (7.5 YR N 3/), very strongly acid loam, rich in raw humus, fine to medium crumb strong structure. It has a nonsticky, nonplastic consistence when wet and is loose when moist or dry.

A_{21} -- 8-15 cm -- Very dark grey (7.5 YR N 3/) very strongly acid sandy loam, very fine crumb, moderate structure. When wet this soil is nonsticky and nonplastic, is very friable when moist and soft when dry.

A_{22} -- 15-30 cm -- Light brownish-grey (10 YR 6/2), very strongly acid sandy loam. The structure is medium, subangular blocky, moderate grade. The consistence sticky, plastic when wet, firm when moist, slightly hard when dry, showing weak cementation.

B_{1t} -- 30-45 cm -- Brownish-yellow (10 YR 6/8), very strongly acid clay, with medium, blocky, moderate structure. It is slightly sticky, slightly plastic when wet, firm when moist, and slightly hard when dry with weak cementation. Reddish mottlings are present.

B_{2t} -- 45-65 cm -- Yellow (10 YR 7/8), strongly acid clay, with reddish mottling, subangular blocky to massive structure. The soil was very sticky and plastic when wet, firm when moist and hard when dry with strong cementation.

B_{3t} -- 65-90 cm -- Very pale brown (10 YR 7/4), strongly acid clay, strongly mottled. Structure is massive and the consistence is very sticky and plastic when wet, very firm when moist and very hard when dry, graded to indurated.

Profile VI. Puletan loamy sand.

Location: Savanna Forest Division, Mango Creek Forest Reserve.

Description: Soil is an unsuccessful *P. caribaea* plantation of 1952. Trees are stunted, having a bad shape, about only 3 m tall, and sparsely scattered. Undergrowth is composed of grass, crabboo, black maya, palmetto. The parent material is coastal deposit. The relief is flat at 6 m elevation. The soil is shallow with a slow external and impeded internal drainage.

New Classification: Order .... Ultisols

Suborder ..... Aquults

Horizons

A_1 -- 0-10 cm -- Very dark gray (2.5 YR N 3/), very high in organic matter, loamy sand and is very strongly acid. The structure is fine to medium crumb, with strong aggregates, nonsticky and nonplastic when wet, very friable when moist and soft when dry

A_2 -- 10-25 cm -- Gray (7.5 YR N 5/), strongly acid loamy sand. The structure is medium granular and weak and the consistence nonsticky, nonplastic when wet and loose when moist and dry.

B_{1g} -- 25-43 cm -- Light grey (10 YR 7/2), very strongly acid, gleyed, sandy clay. The structure is medium granular and weak. The consistence slightly sticky and slightly plastic when wet, firm when moist, and hard when dry. It looks to be strongly cemented.

B_{2g} -- 43-60 cm -- Very pale brown (10 YR 7/3), very strongly acid, gleyed and mottled clay, with a massive structure. The consistence is very sticky and very plastic when wet, extremely firm when moist and very hard when dry and graded down to indurated

Profile VII: Granadoro sandy clay loam

Location: Melinda Forest Division, Grants Work Forest Reserve.

Description: Soil under well developed *P. caribaea* plantation of 1951, in Broken Pine Ridge formation. Parent material is sandstone and shale. Relief is normal at 50 m elevation. The soil is 1.20 m deep. External drainage is moderate and internal drainage is slow. Undergrowth is dominated by polewood (*Xylopia*) and maya (*Bicenia*).

New Classification: Order ...... Oxisols

Suborder ...... Orthox

Horizons:

A_1 -- 0-18 cm -- Olive brown (2.5 Y 4/4), strongly acid, humus sandy clay loam, having a medium and coarse crumb structure with moderate strong aggregates. The consistence is slightly sticky, nonplastic when wet, friable when moist and soft when dry

A_2 -- 18-23 cm -- Dark red brown (10 YR 3/4), strongly acid, humus sandy loam, with very fine crumb and single grain structure. The consistence is nonsticky and nonplastic when wet, loose when moist and dry

B_1 -- 23-40 cm -- Light red (10 R 6/6), strongly acid sandy loam. The structure is between fine granular and single grain. The soil is nonsticky and nonplastic when wet, loose when moist and dry.

B_{2t} -- 40-65 cm -- Red (10 R 45/6), very strongly acid clay. The structure is massive grain and the consistence sticky, plastic when wet and loose when moist and dry.

B_{3t} -- 65-100 cm -- Light red (10 R 6/6), strongly cemented massive clay.

Profile VIII: Silkgrass sandy loam

Location: Melinda Forest Division, Grants Work Forest Reserve, increment plot 12.

Description: Hurricane blown pine plantation of 1945, with dense undergrowth. Parent material is residual granite. Terrain is situated on a gentle slope at 50 m elevation. The soil is very deep and undergoes a slight surface erosion. The internal and external drainage are very good.

New Classification: Order .... Oxisols

Suborder .... Orthox

Horizons:

A_1 -- 0-15 cm -- Very dark grey brown (2.5 YR 3/2), very humic and strongly acid sandy loam, with very fine, strong, crumb structure. The consistence is nonsticky and nonplastic when wet, loose when moist and dry.

A_2 -- 15-30 cm -- Dark brown (7.5 YR 3/2), medium acid, loamy sand, with large amounts of humus having a single grain structure. The consistence is nonsticky, nonplastic when wet, loose when moist and dry.

B_1 -- 30-55 cm -- Reddish-yellow (7.5 YR 7/8), medium acid loamy sand having a weak very coarse granular to single grain structure. Soil is nonsticky and nonplastic when wet, loose when moist and dry

B_{21} -- 55-80 cm -- Yellow (10 YR 7/8), medium acid loamy sand, with fine granular to single grain structure. The consistence is nonsticky, nonplastic when wet, loose when moist and dry

B_{22} -- 80-124 cm -- Brownish-yellow (10YR 6/8), strongly acid sandy loam with a fine granular weak structure, sometimes single grain. The consistence is nonsticky, nonplastic when wet, loose when moist and dry.

B_3 -- 124+ cm -- Reddish-yellow (7.5 YR 6/8), strongly acid sandy clay loam. Soil has a coarse blocky structure with weak aggregation, almost massive. The consistence is sticky and plastic when wet, very firm when moist and hard when dry, grading to indurated

Profile IX: Silkgrass sand.

Location Melinda Forest Division, Grant Work Forest Reserve.

Description Soil under *P. caribaea* plantation of 1943, with undergrowth composed of shrubs, oak, palmetto, dumb cane, cotton grass, craboo, sirin. Parent material is river alluvium. The elevation is 50 m, subnormal to flat relief. Soil is moderately deep and the internal and external drainage is slow.

New Classification: Order . . . . Oxisols

Suborder . . . . . Aquox

Horizons:

A_1 -- 0-13 cm -- Very dark grey-brown (2.5 Y 3/2), very strongly acid, and rich in humus. It has a single grain structure. The consistence is nonsticky, nonplastic when wet, loose when moist and dry.

A_2 -- 13-30 cm -- Grayish-brown (10 YR 5/2), strongly acid sandy loam with a granular weak to single grain structure and nonsticky, nonplastic when wet, loose when moist and dry.

B_1 -- 30-52 cm -- Pale yellow (2.5 Y 8/4), strongly acid and heavily leached sandy loam, having a granular structure with moderate aggregation. The consistence is nonsticky, nonplastic when wet, loose when moist and dry.

B_{21t} -- 52-67 cm -- Very pale brown (10 YR 7/4), strongly acid, mottled sandy clay loam having a fine granular weak structure. The soil is sticky, and plastic when wet, firm when moist, hard when dry and weakly cemented.

B_{22t} -- 67-83 cm -- Brownish-yellow (10 YR 6/6), very strongly acid, massive red mottled clay. The consistence is sticky and plastic when wet, extremely firm when moist and very hard when dry, grading to indurated.

Profile X. Sirie loamy sand.

Location. Meliede Forest Division, Meliede Forest Reserve

Description. Soil under natural regularly burnt pine stand, with an undergrowth composed of shrubs, oak, crabboo, palmetto. Parent material is granite. Terrain has a gentle slope and elevated 20 m above sea level. The soil is deep. Pebbles sparsely present in B Horizon. Internal and external drainage are good.

New Classification. Order ...... Oxisols

Suborder ...... Udults

Horizons.

A_1 -- 0-13 cm -- Dark grey (2.5 YR N 4/), very strongly acid, loamy sand with much humus. The structure is between granular and single grain. It has a nonsticky, nonplastic when wet, loose when moist and dry consistence.

A_{21} -- 13-20 cm -- Light brownish-gray (10 YR 6/2), very strongly acid, heavily leached loamy sand with fine single grain structure. Soil is nonsticky and nonplastic when wet and loose when moist and dry.

A_{22} -- 20-45 cm -- White (2.5 Y 8/2), very strongly acid, leached loamy sand having single grain structure. The soil consistence is nonsticky, nonplastic when wet and loose when moist and dry.

B_{1t} -- 45-75 cm -- Pale yellow (2.5 Y 8/1), very strongly acid, leached sandy loam with medium crumb weak structure. The consistence is nonsticky and nonplastic when wet and loose when moist and dry and is weakly cemented.

B_{2t} -- 75-85 cm -- Yellow (10 YR 7/8), strongly acid sandy loam. Its structure is medium granular and weak. The consistence is sticky and slightly plastic when wet, firm when moist and hard when dry with strong cementation.

Profile XI. Melinda loamy sand

Location: Melinda Forest Division, Melinda Forest Reserve.

Description: Soil under natural P. caribaea stand with undergrowth composed of shrubs, grass and yaha. Parent material is alluvium. The site has a flat relief at an elevation of 15 m. The soil is moderate deep and internal and external drainage are good.

New Classification: Order .... Entisols

Suborder .... Fluvents

Horizons:

A_{11} -- 0-5 cm -- Black (2.5 YR N 2/), very strongly acid loamy sand with raw humus. The structure is single grain and the consistence nonsticky, nonplastic and loose.

A_{12} -- 5-13 cm -- Dark brown (7.5 YR 4/4), strongly acid, humus, sandy loam, rich in humus having fine crumb, weak structure. The consistence is slightly sticky and nonplastic when wet, loose when moist and dry.

A_2 -- 13-25 cm -- Brown (7.5 YR 5/4), strongly acid, humic loamy sand. It has a granular weak structure. The consistence is slightly sticky, nonplastic when wet, very loose when moist and dry.

B_1 -- 25-55 cm -- Pale yellow (2.5 YR 8/4), slightly acid and leached loamy sand with fine to medium crumb, weak structure. The soil has a consistence which is slightly sticky and nonplastic when wet, very loose when moist and is weakly cemented.

B_2 -- 55-72 cm -- Yellow (10 YR 7/8), slightly acid loamy sand, having a medium crumb, weak structure. The consistence is slightly sticky and nonplastic when wet, loose when moist and dry. The soil is weakly cemented.

Profile XII Macapina loamy sand

Location. Melinda Forest Division, Melinda Forest Reserve.

Description. Soil under regularly burnt natural P. caribaea stand with undergrowth of sirin, crabboo and yaha. Parent material is colluvium. The relief is subnormal, flat topography at 10 m elevation. The soil is very shallow and has a stagnant internal and external drainage.

New Classification. Order . . . . . Entisols

Suborder . . . . Aquents

Horizons

A_1 -- 0-15 cm -- Very dark grey (10 YR 3/1), very strongly acid loamy sand with raw humus. The structure is single grain and the consistence is nonsticky, nonplastic when wet and loose when moist.

A_2 -- 15-30 cm - White (10 YR 8/2), strongly acid, leached sandy loam. It has a medium granular, weak structure. The consistence is sticky and slightly plastic when wet, firm when moist and hard when dry with strong cementation.

B_1 -- 30+ cm -- White (2.5 Y 8/2), slightly acid, leached sandy loam with a fine granular weak structure. The consistence is slightly sticky and plastic when wet, firm when moist, hard when dry with strong cementation.
Deeper sampling is impossible because of high groundwater

Profile XIII. Pinol gravelly clay (hill soil).

Location: Mountain Pine Ridge (north of Naval Road)

Description: Soil under natural P. caribaea stand, which is frequently burnt. Trees are sparsely distributed and the soil is covered with short wire grass. Parent material is probably metamorphic rock (shale). It has a strongly rolling to moderately steep relief. The slope is gentle with east aspect at 500 m elevation. The soil is very deep and appeared to be penetrable to roots to great depth. There are signs of gully erosion. The soil is rich in pebbles and gravel (red) throughout the profile and boulders on the surface. The soil is very deep, with a moderate lateral drainage.

New Classification: Order ...... Ultisols
Suborder ...... Humults

Horizons

A_2 -- 0-8 cm -- Light grey (2.5 Y 7/2), extremely acid gravelly clay which is subject to leaching. It has a coarse, subangular, blocky, weak structure. The consistence is plastic when wet, firm when moist and hard when dry with strong cementation.

B_{1t} -- 8-23 cm -- Reddish-yellow (7.5 YR 7/6), very strongly acid clay, having a subangular blocky weak structure. The consistence is sticky and plastic when wet, hard when dry with strong cementation.

B_{2t} -- 23-47 cm -- Reddish-yellow (7.5 YR 7/8), very strongly acid clay with a massive structure. The soil consistence is sticky and plastic when wet, extremely firm when moist and extremely hard when dry, grading to indurated.

B_{3t} -- 47-92 cm -- Red (10 R 4/8-5/8), very strongly acid clay loam, with a massive structure. The consistence is sticky and plastic when wet, extremely firm when moist and extremely hard when dry, grading to indurated

C -- 92+ cm -- Parent material

Profile XIV. Tok loamy sand.

Location: Northern Pine Ridge (about 5 km east of ferry landing stage in New River).

Description: Soil under a vegetation composed of savanna grass, sparse P. caribaea in clumps, chaparro (Curatella americana), sakate (Scleria bracteata), muk (Dalbergia glabra), crabboo (Byrsonima crassifolia), Leucaena pulverulenta. The parent material is coastal deposit and siliceous limestone. The relief is flat at 10 m elevation. The soil is moderately deep. External drainage is slow, but internal drainage is somewhat slow.

New Classification. Order ...... Alfisols

Suborder ...... Aqualfs

Horizons:

A_1 -- 0-13 cm -- Dark gray (2.5 Y N 4/), strongly acid, loamy sand with much humus. Soil has a single grain structure.

A_2 -- 13-23 cm -- Gray (10 YR 6/1), slightly acid, leached sand with single grain structure.

B_{1t} -- 23-30 cm -- Light grey (5 Y 7/2), very strongly acid, leached sandy loam. The structure is medium crumb with moderate aggregation. The consistence is nonsticky, nonplastic when wet, friable when moist and soft when dry with weak cementation.

B_{2t} -- 30+ cm -- Pale yellow (5 Y 7/3), extremely acid, leached sandy clay loam. The structure is medium granular and weak. The consistence is sticky, plastic when wet, firm when moist, and hard when dry with strong cementation. A reddish mottling is present.

APPENDIX 111

Koppen's Classification of Climates*

In his classification Koppen recognizes five main climatic groups which are intended to correspond to five broad vegetation types. These five climatic groups are designated by capital letters as follows:—

A: Tropical rainy climates with no cool season.

B: Dry climates.

C: Middle latitude rainy climates with mild winters.

D: Middle latitude rainy climates with severe winters.

E: Polar climates with no warm season.

The following is a summary of Koppen's A and C climatic groups which have been referred to in this paper:—

A Climates

Tropical rainy climates with the average temperature of the coolest month above 18 C. Within this group there are two distinct types. In the one there is adequate precipitation throughout the year, while in the other there is a distinct dry season(s).

Af: Tropical rain forest climates in which a minimum of 6 cm of rain falls during the driest month. Seasonal variations in temperature and precipitation within this climate are at a minimum and both remain at a high level throughout the year.

---

*After Trewartha (1954). Appendix A, p 381; cited from Luckhoff (1964).

Aw: Tropical savanna climates with a distinct winter dry season. Savanna climates are characterized by a marked seasonal rainfall rhythm and at least one month must have less than 6 cm of rain. Temperature similar to Af.

Aw': Similar to Aw with rainfall maximum in autumn.

Aw'': Similar to Aw but with two distinct rainfall maxima separated by two dry seasons.

Amw: Tropical savanna climate with a short dry season, but with such a high total rainfall that the ground remains sufficiently wet throughout the year to support tropical rain forest.

Amw'': Same as Amw but with two short dry seasons and an average temperature range between the warmest and coldest months of less than 5 C.

C Climates

Warm temperate rainy climates with the average temperature of the coldest month below 18 C but above -3 C, and the average temperature of the warmest month above 10 C. Within this climatic group there are three distinct, contrasting rainfall regimes, namely the f type with no dry season, the w type with a dry winter, and the s type with a dry summer.

Cf: No distinct dry season, more than 3 cm of precipitation during the driest month. The difference in precipitation in the case of the wettest and driest months is less than in the case of the Cw climates.

Cw: Dry winter with at least ten times as much rain in the wettest month of the summer as in the driest month of the winter.

In low latitudes this climatic type is found in areas where altitude has reduced the temperature of the Aw xlimate which prevails in the adjacent lowlands.

APPENDIX lV

The Four Elements in the Thornthwaite Classification of Climates (from Carter and Mather 1966)

Element 1: Moisture Provinces

Moisture Province		Moisture index
A	Perhumid	100 and above
B_4	Humid	80 - 99.9
B_3		60 - 79.9
B_2		40 - 59.9
B_1		20 - 39.9
C_2	Moist Subhumid	0 - 19.9
C_1	Dry Subhumid	-33.3 - 0
D	Semiarid	-66.7 to -33.2
E	Arid	-100 to -66.6

Element 2: Thermal Provinces

Thermal Province		Annual Potential Evapotranspiration	
		Depth of water used -cm-	Energy available -kg cal-
A	Megathermal	>114.0	>66.7
B'$_4$	Mesothermal	99.8 - 114.0	58.5 - 66.7
B'$_3$		85.6 - 99.7	50.1 - 58.4
B'$_2$		71.3 - 85.5	41.9 - 50.0
B'$_1$		57.1 - 71.2	33.4 - 41.7
C'$_2$	Microthermal	42.9 - 57.0	25.1 - 33.3
C'$_1$		28.5 - 42.7	16.7 - 25.0

Thermal Province		Annual Potential Evapotranspiration	
		Depth of water used -cm-	Energy available -kg cal-
D'	Tundra	14.2 - 28.6	8.4 - 16.6
E'	Frost	0 - 14.2	0 - 8.3

Element 3: Seasonal Variation of Effective Moisture

Moisture Provinces (A, B, C_2)		Aridity index
r	little or no water deficiency	0 - 9.9
s	moderate summer water deficiency	10 - 19.9
w	moderate winter water deficiency	10 - 19.9
s_2	large summer water deficiency	20+
w_2	large winter water deficiency	20+

Moisture Provinces (C_1, D, E)		Humidity index
d	little or no water surplus	0 - 16.6
s	moderate winter water surplus	16.7 - 33.2
w	moderate summer water surplus	16.7 - 33.2
s_2	large winter water surplus	33.3+
w_2	large summer water surplus	33.3+

Element 4: Summer Concentration of Energy

Available energy in summer %	Summer concentration type
<48.0	a'
48.0 - 51.8	b'_4
51.9 - 56.2	b'_3
56.3 - 61.5	b'_2
61.6 - 67.9	b'_1
68.0 - 76.2	c'_2
76.3 - 87.9	c'_1
>88.0	d'_1

LITERATURE CITED

Ahmed, N. 1960. Aluminum toxicity of certain soils on the coast of British Guyana and problems of their agricultural utilization. Int. Congr. Soil Sci. Trans., 7th (Madison, Wis.) 2:161-170.

Allen, M. B., and D. I. Arnon. 1955. Studies on nitrogen fixing blue-green algae. II. The sodium requirement of *Anabaena cylindrica*. Physiol. Plant. 8:653-658.

Annual Report Government of Sarawak. Years 1954, 1955, 1957, 1958, 1959, 1961, and 1962. Her Majesty's Stationary Office, London.

Anonymous. 1962. Seminar and study tour of Latin American conifers. Pub. Esp. Inst. Nac. de Invest. Forest. Mexico 1.

A. O. A. C. (Association of Official Agricultural Chemists). 1945. Official and tentative methods of analysis. 6th ed. Washington, D. C. p. 27.

Balci, A. N. 1964. Physical, chemical and hydrological properties of certain western Washington forest floor types. Diss. Abstr. 25: 726-727.

Baldwin, M., C. E. Kellogg, and J. Thorp. 1938. Soil classification, p. 979-1001. *In* Soils and Men. U.S. Dep. Agr. Yearbook of Agriculture 1938, Washington, D.C.

Branson, F. A., R. F. Miller, and I. S. McQueen. 1965. Plant communities and soil moisture relationship near Denver, Colorado. Ecol. 46: 311-319.

Barrett, W. H. G., and L. Golfari. 1962. Description of two new varieties of *Pinus caribaea* Morelet. Carib. Forest. 23:59-71.

Bates, T. F. 1962. Halloysite and gibbsite formation in Hawaii. Clays and Clay Minerals, Proc. 9th Nat. Conf., Pergamon Press, New York 9:315-328.

Baur, G. N. 1958. A soil survey of a slash pine plantation, Barcoongere, N.S.W. Aust. Forest. 23:78-87.

Beard, J. S. 1953. The savanna vegetation of northern tropical America. Ecol. Monogr. 23:149-215.

Beaven, P. J., and M. J. Dumbleton. 1966. Clay minerals and geomorphology in four Caribbean islands. Clay Mineral. 6:371-382.

Becking, J. H. 1960. Der Anbau von *Pinus merkusii* in den Tropen. Schweiz. Zeitschr. f. Forstw. 101:181-191.

Beekman, H. A. J. M. 1949. Houtteelt in Indonesie. Veenman and Zonen, Wageningen.

Bertrand, A. R., and H. Kohnke. 1957. Subsoil conditions and their effects on oxygen supply and the growth of corn roots. Soil Sci. Soc. Amer. Proc. 21:135-140.

Blake, G. R. 1965a. Particle density, p. 371-373. *In* C. A. Black (ed.) Methods of soil analysis. Amer. Soc. Agron., Inc., Madison, Wis.

________. 1965b. Bulk density, p. 373-377. *In* C. A. Black (ed.) Methods of soil analysis. Amer. Soc. Agron., Inc., Madison, Wis.

Blank, F. 1958. Anthocyanins, flavones, xanthones. p. 300-354. *In* W. Ruhland (ed.) Encyclopedia of plant physiology, Vol. 10. Springer Verlag, Berlin.

Blumenstock, D. I. 1958. Distribution and characteristics of tropical climates. Pacif. Sci. Congr. Proc., 9th (Bangkok, Thailand) 20:3-24.

Bould, C. 1963. Trends in the inorganic nutrification of plants, p. 1-96. *In* F. C. Steward (ed.) Plant physiology: a treatise, Vol. 3. Academic Press, New York.

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analyses of soils. Agron. J. 54:464-465.

Briscoe, C. B. 1959. Early result of mycorrhizal inoculation of pine in Puerto Rico. Carib. Forest. 20:73-77.

British Honduras. 1965. Report for the years 1962-63. Belize City Printing Department, Belize.

Britton, N. L. 1908. North American trees. Henry Holt and Co., New York. p. 35-37.

Broadbent, F. E. 1957. Organic matter, p. 151-157. *In* Soil. U.S. Dep. Agr. Yearbook of Agriculture 1957, Washington, D.C.

Brzesowski, W. J. 1962. Podzolic and hydromorphic soils in a coastal plain in the Cameroon Republic. Neth. J. Agric. Sci. 10:145-153.

Budowski, G. 1956. Tropical savannas, a sequence of forest clearings and repeated burnings. Turrialba 6:23-33.

________. 1964. Holdridge's world classification of life zones: a reappraisal. Turrialba 14:98-100.

________ 1965. The choice and classification of natural habitats in need of preservation in Central America. Turrialba 15:238-249.

Bushong, A. D. 1961. Agricultural settlement in British Honduras: a geographic interpretation of its development. Ph.D. Diss. Univ. Florida, Gainesville.

Carrodus, B. B. 1967. Absorption of nitrogen by mycorrhizal roots of beech. II. Ammonium and nitrate as sources of nitrogen. New Phytol. 66:1-4.

Carter, D. B., and J. R. Mather. 1966. Climatic classification for environmental biology. Pub. Climatology 19(4):305-395.

Carter, M. C., and L. R. Jones. 1962. The effect of hydrogen peroxide on the germination of loblolly and slash pine seed. U.S. Dep. Agr. Forest Serv., Southeast. Forest Exp. Sta., Pap. 141.

Chapman, H. D. 1965. Cation-exchange capacity, p. 891-901. In C. A. Black (ed.) Methods of soil analysis. Amer. Soc. Agron., Inc., Madison, Wis.

Chapman, V. J. 1962. The algae. Macmillan, London.

Charter, C. F. 1940. A reconnaissance survey of the soils of British Honduras. Govt. Print. Office, Port of Spain, Trinidad.

Chittenden, A. E., G. C. Jerman, E. R. Palmer, and J. F. Hughes. 1967. The pulping properties of *P. caribaea*. Commonw. Forest Rev. 46:22-35.

Cree, C. B. 1954. Annual report of the Forest Department for the year 1953. Govt. Print. Office, Belize.

________ 1956. A pine regeneration scheme for the southern coastal forests of British Honduras. Internal Report.

Denevan, W. M. 1961. The upland pine forests of Nicaragua. Univ. of California, Pub. in Geogr. 12(4):251-320.

Dixon, C. G. 1957. Geology of southern British Honduras with notes on adjacent areas. Govt. Print. Office, Belize.

Donahue, R. L. 1965. Soils, an introduction to soils and plant growth. Prentice-Hall, Inc., Englewood Cliffs, N.J.

d'Silva, D. W. 1949. British Honduras. Report of the Forest Department ended December 31, 1948. Govt. Print. Office, Belize.

Dutil, P., and C. Juste. 1964. Phytotoxicity of aluminum in soils of the Landes in relation to the presence of a hardpan at shallow depth. C. R. Acad. Agr. Fr. 50:434-441 (Abstr. in Soils and Fertil. 27:425).

Eisenmenger, W. S. 1930. Toxicity of aluminium salts to tobacco plants. J. Agr. Res. 41:616-624.

FAO. 1950. Report of the FAO mission for Nicaragua. Washington, D.C.

______. 1962. Estimates of the worlds forest resources. Unasylva 16:123.

______. 1965. Yearbook of Forest Products Statistics. Rome.

Faust, G. T. 1946. Dedolomitization and its relation to possible derivation of magnesium rich hydrothermal solution. Amer. Mineral. 34:789-823.

Ferguson, J. H. A. 1954. Growth and yield of Pinus merkusii in Indonesia. Neth. J. Agric. Sci. 2:197-208.

Fiskell, J. G. A., and V. W. Carlisle. 1964. Differential thermal analysis of some clays and Florida soil clays. Soil and Crop Sci. Soc. Fla. Proc. 24:114-124.

Forest Department. 1966. History of Forestry in British Honduras. Internal Report.

Gasser, J. K. R. 1961. Investigations on rice growing in British Guyana. 1. Characteristics of some rice soils of the coast land. J. Soil Sci. 12:234-241.

Goethals, H. 1967. Pulp-paper mill plan advances in Honduras. Christian Sci. Monitor. 16 Sept.

Geor, C. P. 1965. Afforestation with conifers in Brazil. Ecological aspects of plantations in the South, particularly of Pinus elliottii and Araucaria angustifolia. Min. Agric. Bol. 8, Rio de Janeiro.

Griffiths, D. A. 1965. The mycorrhiza of some conifers grown in Malaya. Malay. Forest. 28:116-121.

Hacskaylo, E. 1967. Mycorrhizae of trees with special emphasis on physiology of ectotrophic types. Ohio J. Sci. 67:350-357.

Haider, A. 1967. Methods applied to survey of pine forests in Honduras, C.A. Medd. Norske SkogforsVesen 84:1-46.

Hancock, M. J. D. 1962. A summary of investigation into the soil types in the plantation area at Mango Creek and the relationship these have on growth. Internal Report.

Hardy, F., H. P. Smart, and G. Rodriguez. 1935. Some soil-types of British Honduras, Central America. Govt. Print. Office, Port of Spain, Trinidad.

Herter, R. D., and E. O. McLean. 1965. The effect of moisture level and incubation time on the chemical equilibria of a Toledo clay loam soil. Agron. J. 57:583-588.

Heinsdorf, D. 1965. The fertilizer needs of Scots pine plantations. Sozial. Forstw., Berl. 15:183-188. (Abstr. in Forest. Abstr. 27, p. 240).

Helbig, K. M. 1959. Die Landschaften von Nordost-Honduras, auf Grund einer geographischen Studienreise im Jahre 1953. Petermanns Geog. Mitt. Ergänzungsheft 268. Veb Hermann Haack, Gotha.

Hellinga, G. 1948. Resultaten van de proeftuinen voor boomgewassen sedert 1937. Coniferen Rep. 23. Boschbouwproefsta., Bogor, Indonesia.

Hewitt, E. J. 1963. The essential nutrient elements. Requirements and interactions in plants, p. 137-360. *In* F. C. Steward (ed.) Plant Physiology. a treatise, Vol. 3. Academic Press, New York.

Heyligers, P. C. 1963. Vegetation and soil of a white sand savanna in Suriname. Noord Holl. Uitg. Mij., Amsterdam.

Holdridge, D. A., and F. Vaughan. 1957. The kaolin minerals (kandites), p. 98-139. *In* R. C. Mackenzie (ed.) Differential thermal investigation of clays. Mineral. Soc., London.

Holdridge, L. R. 1947. Determinations of world plant formations from simple climatic data. Science 105:367-368.

Hummel, C. 1921. Report on the forests of British Honduras, with suggestions for a far reaching forest policy. Reprod. by Forest Trust British Honduras, 1925, Belize.

Hunt, D. R. 1962. Some notes on the pines of British Honduras. Emp. Forest Rev. 41:134-145.

Jackson, M. L. 1958. Soil chemical analysis. Advanced course. Publ. by the author, Madison, Wis. p. 265-270.

——— 1958. Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, N.J.

——— 1965. Clay transformation in soil genesis during the Quaternary. Soil Sci. 99:15-22.

Jenny, H. 1950. Causes of the high nitrogen and organic matter content of certain tropical forest soils. Soil Sci. 69:63-69.

——— 1961. Reflections on the soil acidity merry-go-round. Soil Sci. Soc. Amer. Proc. 25:428-432.

Johannessen, C. L. 1963. Savannas of interior Honduras. Univ. California Press, Berkeley and Los Angeles.

Keller, W. D. 1964. Processes of origin and alteration of clay minerals. p. 3-79. In C. I. Rich and G. W. Kunze (ed.) Soil clay mineralogy. Univ. North Carolina Press, Chapel Hill.

Kelley, J. D., and R. W. Skier. 1965. Seasonal changes in the macronutrient composition of leaves and stems of *Taxus media*. Amer. Soc. Hort. Sci. Proc. 86:809-814.

Koberg, H. 1966. Düngung und Mykorrhiza. Ein Gefaessversuch mit Kiefern. Forstw. Cbl. 85:371-379.

Kramer, P., and T. T. Kozlowski. 1960. Physiology of trees. McGraw-Hill, Inc., New York. p. 224-275.

Kraus, S. 1964. The magnesium status of soils in the Potsdam, Cottbus and Frankfurt (Oder) districts. Albrecht-Thaer-Arch. 8:323 (Abstr. in Soils and Fertil. 27, p. 488)

Krueger, W. C., Jr. 1963. Mineralogical composition of textural properties of river sediments from British Honduras. Ph.D. Diss. Rice Univ., Houston, Texas.

Laboratory of Climatology. 1963. Average climatic water balance data of the continents. Part 2, Asia (excluding U.S.S.R.). Pub. Climatology 16(1), p. 131.

Lamb, A. F. A. 1948. British Honduras Forest Department: annual report for 1947. Govt. Print. Office, Belize.

______ 1950. Pine forests of British Honduras. Emp. Forest. Rev. 29:219-224.

______ 1959. Impression of tropical pines and hardwoods in some Western countries. Commonw. Forest. Inst., Dept. Forest. Univ. Oxford.

LeCacheux, P. 1957. Report on a preliminary pulp and paper survey in British Honduras, including possibilities for wall board manufacturing. Carib. Com., Kent House, Port of Spain, Trinidad.

Liem, Y. T. 1964. Indonesia: new mills in expansion plan. Pulp and Paper 38(23) 231.

Little, E. L., Jr., and K. W. Dorman. 1952. Slash pine (*Pinus elliottii*), its nomenclature and varieties. J. Forest. 50:918-923.

Lockard, R. C., and H. R. McWalter. 1956. Effect of toxic levels of sodium, arsenic, iron, and aluminium on the rice plant. Malay. Agr. J. 39:259-268.

Lockley, L. C. 1964. A guide to market data in Central America. Centr. Bank Econ. Integr., Tegucigalpa (Honduras).

Longwood, F. R. 1962. Present and potential commercial timbers of the Caribbean, with special reference to the West Indies, the Guyanas, and British Honduras. U.S. Dep. Agr. Handbook 207, p. 82-94.

Loock, E. E. M. 1950. The pines of Mexico and British Honduras, a report on a reconnaissance of Mexico and British Honduras during 1947. S. Africa Dep. Agr. and Forest. Bull. 35, p. 210-213.

Luckhoff, H. A. 1964. The natural distribution, growth and botanical variation of *P. caribaea* and its cultivation in South Africa. D.Sc. F. Thesis. Univ. Stellenbosch, South Africa.

Mackenzie, R. C. 1957. The oxides of iron, aluminium and manganese, p. 299-328. *In* R. C. Mackenzie (ed.) The differential thermal investigations of clays. Mineral. Soc., London.

Martin, J. P., S. J. Richards, and P. F. Pratt. 1964. Relationship of exchangeable Na percentage at different soil pH levels to hydraulic conductivity. Soil Sci. Soc. Amer. Proc. 28:620-622.

McGee, C. E. 1963. A nutritional study of slash pine seedlings grown in sand culture. Forest Sci. 9:461-469.

McGeorge, W. T. 1936. Factors influencing the availability of native soil phosphate fertilizers in Arizona soils. Ariz. Agr. Exp. Sta. Tech. Bull. 62:295-331.

McLeod, L. B., and L. P. Jackson. 1965. Effect of concentration of the aluminium ion on root development and establishment of legume seedlings. Canad. J. Soil Sci. 45:221-234.

McWilliam, J. R., and B. N. Richards. 1954. Caribbean pine (*Pinus caribaea*). Some notes on its development and characteristics in Central America and Caribbean pine in Queensland. Qd. Forest Serv. Res. Note 4.

Metwally, S. Y., and A. G. Pollard. 1959. Effects of soil moisture conditions on the uptake of plant nutrients by barley and on the nutrient content of the soil solution. J. Sci. Food Agr. 10:632-636.

Metz, L. J., C. G. Wells, and B. F. Swindel. 1966. Sampling soil and foliage in a pine plantation. Soil Sci. Soc. Amer. Proc. 30:397-399.

Miller, W. F. 1966. Annual changes in foliar nitrogen and potassium levels of loblolly pine (*Pinus taeda* L.) with site and weather factors. Plant and Soil 24:369-378.

Mirov, N. T. 1961. Composition of gum turpentine of pines. Pacif. Southwest Forest Range Exp. Sta., U.S. Dep. Agr. Tech. Bull. 1239.

Mohr, E. C. J. 1944. The soils of equatorial regions with special reference to the Netherlands East Indies (Transl. by R. L. Pendleton, J. W. Edwards, Ann Arbor, Mich.) p. 383-403.

__________, and F. A. van Baren. 1954. Tropical soils: a critical study of soil genesis as related to climate, rock and vegetation. W. van Hoeve, The Hague.

Morelet, A. 1851. Description de deux nouvelles especes de pins. Revue Horticole de la Cote d' Or 1:105-107.

Morris, Sir D. 1883. The colony of British Honduras, its resources and prospects, with particular reference to its indigenous plants and economic productions. E. Stanford, London.

Mukherji, S. K., and H. S. Tangar. 1961. Mycorrhiza in seven exotic conifers growing in New Forest (Dehra Dun). Indian Forest. 87:486-488.

Murray, P., and J. White. 1955. Kinetics of clay hydration. Clay Mineral. Bull. 2:255-264.

Naval Stores Review, International Yearbook 1958-1966. Publ. by Naval Stores Review, New Orleans, La.

Nikles, D. G. 1962. Tree breeding in Queensland. Brit. Commonw. Forest. Conf.

Office of the Premier. 1964. British Honduras: development plan 1964-1970. Belize.

Ower, L. H. 1928. Geology of British Honduras. J. Geol. 36:497-510.

Parsons, J. J. 1955. The Moskito pine savanna of Nicaragua and Honduras. Ann. Assn. Amer. Geogr. 45:36-63.

Pendleton, R. L. 1945. Some important soils of Central America, p. 163-166. In F. Verdoorn (ed.) Plants and plant science in Latin America. Chron. Bot. 16. Waltham, Mass.

Pritchett, W. L. 1968. Progress in the development of techniques and standards for soil and foliar diagnosis of phosphorus deficiency in slash pine, p. 81-87. In Forest fertilization -- theory and practice. TVA Wilson dam, Ala.

__________, and W. R. Llewellyn. 1966. Response of slash pine (Pinus elliottii var. elliottii) to phosphorus in sandy soils. Soil Sci. Soc. Amer. Proc. 30:509-512.

Pulp and Paper. 1958-1967. Vols. 32-41. Miller Freeman Pub., Inc. New York.

Rehfuess, K. E., and W. Moll. 1965. Orientierende Untersuchungen über den Ernährungszustand von Fichtenbeständen auf Jungmoräne in Oberschwaben. Allg. Forst- u. Jagdztg. 136:211-223.

Richards, B. N., and G. L. Wilson. 1963. Nutrient supply and mycorrhiza development on Caribbean pine. Forest Sci. 9:405-412.

Richards, L. A. 1965. Physical condition of water in soil, p. 375-377. In C. A. Black (ed.) Methods of soil analysis. Amer. Soc. Agron., Inc., Madison, Wis.

Richards, P. W. 1964. The tropical rain forest: an ecological study. Cambridge Univ. Press.

Rin'kis, G. Ya., and Kh. K. Ramane. 1966. Effect of degree of dispersion of medium on uptake of nutrients by buckwheat. Agrokhymya 2:63-72 (Abstr. in Soils and Fertil. 29, p. 378).

Romney, D. H. 1959. Land in British Honduras: report of the British Honduras land use survey team. Colon. Res. Publ. 24. Her Majesty's Stationery Office, London.

——— 1961. Productivity of pastures in British Honduras. II. Pangola pasture, as influenced by climate, soil type and phosphate fertiliser. Trop. Agr. 38:39-47.

Roe, H. B. 1950. Moisture requirements in agriculture, farm irrigation. McGraw-Hill inc., New York.

Rousseau, L. Z. 1965. Forest resources of the world and their implications. Pulp Paper Mag. Can. 66(3) WR 388-WR 390.

Russell, Sir. E. J. 1961. Soil conditions and plant growth. 9th ed. Longmans, London.

Sampson, H. C. 1928. Report on the development of agriculture in British Honduras. Emp. Marketing Board Publ. 16.

Schafer, E. R., and G. H. Chidester. 1961. Pulping and paper making experiments on certain pines of Mexico and Central America. U.S. Dep. Agr., Forest Prod. Lab., Madison, Wis. Rep. 2217.

Schimper, A. F. W. 1903. Plant geography upon a physiological basis (Transl. by W. R. Fisher. Ed. by P. Groom and I. B. Balfour, Clarendon Press, Oxford).

Schroo, H. 1963. An inventory of soils and soil suitabilities in West Irian. II A. Neth. J. Agric. Sci. 11:387-421.

Schulz, J. P. 1960. Ecological studies on rain forest in Northern Surinam. Noord Holl. Uitg. Mij, Amsterdam.

Scott, C. W. 1960. Pinus radiata. FAO Forest and Forest Prod. Stud. 14.

Sen, B. K., and B. Chatterjee. 1967. Clay mineral in the Ganges silt. J. Indian Soil Sci. Soc. 15:325-328.

Seccoleuze. 1957. Conif. 126.

Shaw, G. R. 1914. The genus Pinus. Arnold Arbor. Publ. 5.

Sherman, G. D. 1958. Gibbsite rich soils of the Hawaiian Islands. Hawaii Agr. Exp. Sta. Bull. 118.

Simmons, Ch. S., J. M. Tarano, and J. H. Pinto. 1959. Clasificacion de reconocimiento de los suelos de la Republica de Guatemala. Editorial del Min. de Educacion Publica 'Jose de Pineda Ibarra', Guatemala.

Skyring, G. W., and B. J. Callow. 1962. The physiology and biochemistry of nitrification and denitrification, p. 58-71. *In* A review of nitrogen in the tropics with particular reference to pastures, a symposium. Commonw. Agr. Bur., C.S.I.R.O.

Standley, P. C., and S. J. Record. 1936. The forests and flora of British Honduras. Field Mus. Nat. Hist. Pub., Bot. Ser. 12.

______, and J. A. Steyermark. 1945. The vegetation of Guatemala, a brief review, p. 275-278. *In* F. Verdoorn (ed.) Plants and plant science in Latin America. Chron. Bot. 16. Waltham, Mass.

Stevens, R. L. 1964. The soils of Middle America and their relation to Indian peoples and cultures, p. 265-315. *In* R. Wauchope (ed.) Handbook of Middle American Indians. Univ. Texas Press, Austin.

Stevenson, N. S. 1936. Report of the Forest Trust for the year ending December 31, 1935. Govt. Print. Office, Belize.

______. 1937. Report of the Forest Department British Honduras for the year 1936. Govt. Print. Office, Belize.

______. 1939. Report of the Forest Department for the year ended December 31, 1938. Govt. Print. Office, Belize.

______. 1942. Abridged report of the Forest Department for the year ended December 31, 1941. Govt. Print. Office, Belize.

Stewart, W. D. P. 1967. Nitrogen fixing plants. Science 158:1426-1431.

Strebel, O. 1960. Mineralstoffernahrung und Wuchsleistung von Fichtenbestanden (*Picea abies*) in Bayern. Forstwiss. Cbl. 78:17-42.

Streets, R. J. 1962. Exotic forest trees in the British Commonwealth. Clarendon Press, Oxford, p. 474-475.

Taylor, B. W. 1962. The status and development of the Nicaraguan pine savannas. Carib. Forest. 23:21-26.

Thompson, J. E. S. 1954. The rise and fall of Maya civilization. Univ. Okla. Press, Norman.

Tisdale, S. L. and W. L. Nelson. 1967. Soil, fertility and fertilizers. Macmillan, New York.

Trewartha, G. T. 1954. An introduction to climate. McGraw-Hill, Inc. New York.

U.S. Dep. Agr. Soil Survey Staff. 1951. Soil Survey Manual. Handbook 18. Washington, D.C.

________ 1967 Supplement to soil classification system (7th Approximation). Washington, D C.

Van Steenis, C G G J 1958 Tropical lowland vegetation. The characteristics of its types and their relations to climate. Pacif Sci Congr Proc, 9th (Bangkok, Thailand) 20:25-36.

Van Suchtelen, N J 1962 Mycorrhiza on *Pinus* spp. in the tropics. Meded LandbHogesch. Gent 27:1104-1106.

Verstoegh, P J D 1966. *Pinus caribaea* plantations in Surinam. Paper, World Forest. Congr, 6th (Madrid, Spain).

Vieira, V 1967. *Pinus caribaea* on the white sands in Guyana. Commonw. Forest. Rev. 46:317-322.

Villiers, J M de 1965. Present soil forming factors and processes in tropical and subtropical regions. Soil Sci. 99:50-57

Voorhees, W B, R R Allmaras, and W E Larson. 1966. Porosity of surface soil aggregates at various moisture contents. Soil Sci. Soc. Amer Proc 30:163-167.

Vozzo, J A, and E Hacskaylo. 1961. Mycorrhizal fungi on *Pinus virginiana* Mill. Mycologia 53:538-539.

________, and ________. 1964 Anatomy of mycorrhizas of selected eastern forest trees. Torrey Bot. Cl. Bull. 91:378-387

Walkley, A., and I A Black 1934 An examination of the Detjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37:29-38

Wall, J R D. 1964. Topography-soil relationships in lowland Sarawak. J. Trop. Geogr 18:142-168.

Wardlaw, C W 1929. Panama disease of bananas. Emp Marketing Board Publ. 20.

Wells, C G, and L J Metz. 1963. Variation in nutrient content of loblolly pine needles with season, age, soil and position of the crown. Soil Sci Soc. Amer Proc 27:90-93.

Whittig, L D. 1965. X-ray diffraction techniques for mineral identification and mineralogical composition, p 671-698. *In* C A Black (ed.) Methods of soil analysis. Amer Soc. Agron., Inc., Madison, Wis.

Wiersma, D. 1959 The soil environment and root development, p. 43-51. *In* A. G Norman (ed.) Advan. Agron. 11. Academic Press, New York.

Wilde, S A 1958. Forest soils, their properties and relation to silviculture. Ronald Press Co., New York.

______. 1966. Soil standards for planting Wisconsin conifers. J. Forest. 64:389-391.

Wilson, A. W. 1966. Pulp, paper break records again. Pulp and Paper 40(29):8-10.

Wise, H. 1958. Agricultural possibilities in Honduras. Ceiba 7:1-43.

Wolffsohn, A. 1967. Post hurricane forest fires in British Honduras. Commonw. Forest. Rev. 46:233-238.

Wood, T. W. W., and P. H. T. Beckett. 1961. Some Sarawak soils. II. Soils of the Bintulu coastal areas. J. Soil Sci. 12:218-233.

Worley, J. F., and E. Hacskaylo. 1959. The effect of available soil moisture on the mycorrhizal association of Virginia pine. Forest Sci. 5:267-268.

Young, H. E. 1940. Mycorrhiza and the growth of Pinus and Araucaria. J. Aust. Inst. Agric. Sci. 6:21 (Abstr. in Forest. Abstr. 2, p. 188)

______, P. N. Carpenter, and R. A. Altenberger. 1965. Preliminary tables of some chemical elements in seven tree species in Maine. Maine Agr. Exp. Sta. Bull. 20.

BIOGRAPHICAL SKETCH

Zoefri Hamzah was born November 4, 1922, at Langsa, in the province of Acheh, Island of Sumatra, Indonesia. In 1938, he graduated from the Meer Uitgebreid Lager Onderwijs (Junior High School) in Banda Acheh. He received his initial professional training in the field of Forestry from 1939 to 1941, at the Middelbare Bosbouw School in Madiun, a requirement for intermediate positions in the former Dutch East Indies Forestry Service. From 1941 to 1950, he served in the Forestry Service successively as Forest Ranger and Sub Forest Conservator in Banda Acheh and Meulaboh, Acheh. After the transfer of sovereignty to the Republic of Indonesia in 1950, he took courses at the Akademi Kehutanan designed to train nationals to replace Dutch personnel in the Forestry Service. He graduated in 1952. From 1952 to 1958, he held the rank of Forest Conservator for the Western Division of Kalimantan (Borneo) and was stationed in Pontianak.

In March, 1958, he left the Forestry Service and joined the staff of the School of Forestry, University of Indonesia (later under the administration of the Institut Pertanian Bogor) in Bogor. Here he had the opportunity to register as a regular student, starting as a freshman. He completed his studies in May, 1964, with a major in Silviculture and a minor in Plant Physiology and was awarded the degree of Insinjur Kehutanan (Ir.).

In May, 1964, he came to the U. S. A. under the sponsorship of the

University of Kentucky, Office of Overseas Programs. In September of that year he registered as a graduate student in the School of Forestry, University of Florida, and graduated in April, 1966, with the degree of Master of Science in Forestry.

After the graduation to the present time he enrolled as a graduate student, in the Department of Soils, University of Florida, and has pursued his work toward the degree of Doctor of Philosophy.

He was married in 1946, to the former Sitti Zaeibar, and they have one daughter, Sitti Zaidar, born in 1947, who is now a student in the School of Animal Husbandry, Institut Pertanian Bogor.

He is a member of Xi Sigma Pi, Forestry honorary fraternity and Gamma Sigma Delta, Agricultural honorary fraternity and is an associate member of the Society of Sigma Xi.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August, 1968

Dean, College of Agriculture

Dean, Graduate School

Supervisory Committee:

Chairman

W. H. Smith
C. F. Eno
Hugh Popenoe
H. B. Clark